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68 DATA BOOK (OK)

ELEKTOR ELECTRONICS

THE INTERNATIONAL
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May 1994
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Low-voltage
CMOS devices

DIFFERENTIAL PROBE FOR OSCILLOSCOPES

Morse decoder

Stamp BASIC Computer

General purpose sensor monitor

80C535 Course-Part 3



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- 80C535 SBC extension board
- I²C bus booster
- RS485 interface
- Heat sinks – how and when to use them
- The IL300 linear optoisolator
- RC active filters
- Intelligent EPROM eraser
- Fuel consumption monitor for injection engines
- and more for your continued interest

Front cover

The photograph shows the differential probe described on page 22 being used to ascertain the waveform across an incandescent light bulb. The probe overcomes several shortcomings of the probe supplied with many oscilloscopes. It is a 10:1/100:1 design that enables floating measurements to be carried out. It is suitable for measuring high voltages.

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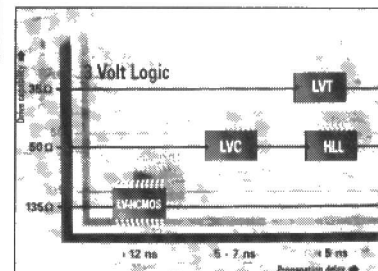
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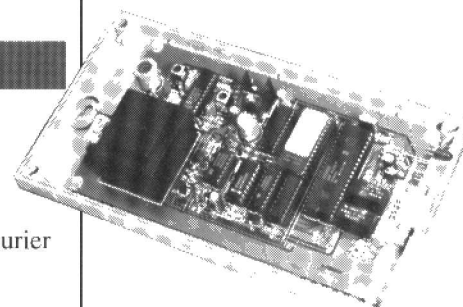
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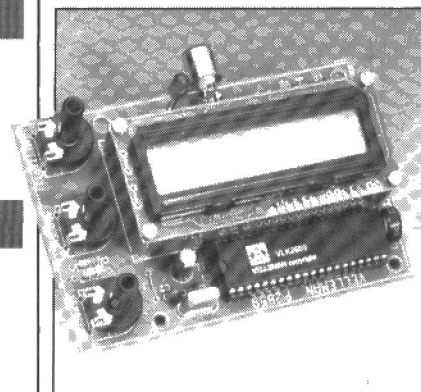
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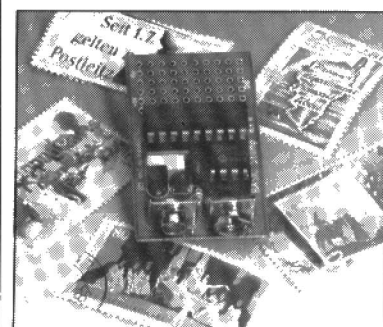
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One sector of the electronics market continues to demand faster and more powerful personal computers. Another demands a longer life from one battery charge in case of portable computers: 2–3 hours is now a minimum. Such demands are not restricted to computers: they apply equally to portable radio receivers, radio telephones and instrumentation equipment. At the same time, the world needs a more efficient use of energy. These conflicting demands force designers of electronic components to bring out ever faster, smaller and more energy-friendly devices. A logical consequence of this is that ICs are becoming smaller and smaller. This in turn means that their dissipation becomes a problem.

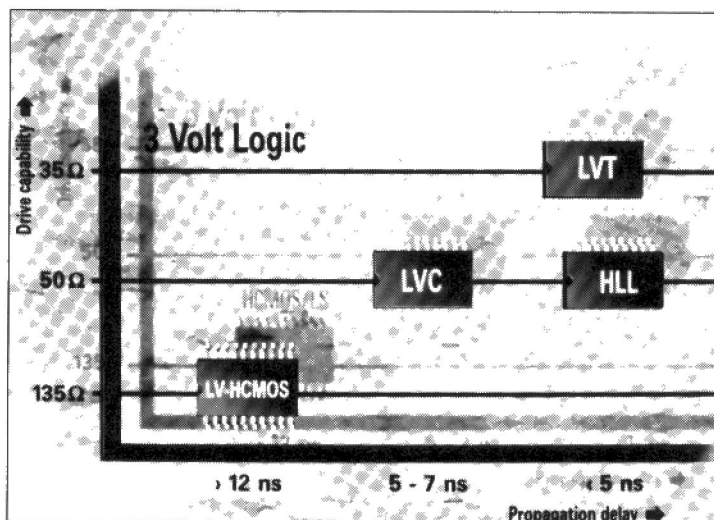
All these requirements have resulted in a lowering of the traditional 5-V supply voltage to 3.3 V (JEDEC standard for mains-operated equipment). Low-voltage versions of 80386 and 680x0 processors, memories, ASICs, disc controllers, LCD controllers, data converters and regulators are already available.

This article takes a closer look at a number of low-voltage families of CMOS logic devices from Philips. Each of these families has a unique product differentiator.

- LV-HCMOS is a 3.3 V medium-speed CMOS family that is compatible with LS and HCMOS.
- LVC is a 3.3 V CMOS logic family that is compatible with FAST, ACL, (Q)FACT and ALS.
- HLL is the world's fastest CMOS family with centre supply pinning and provid-

LOW-VOLTAGE CMOS DEVICES

By our editorial staff



ing low skew, low EMI and a speed as FCT-C.

- ALVC is basically the Multi-byte™ version of HLL.
- LVT is a 3.3 V BiCMOS family that is optimized for driving backplanes and provides live insertion/auto three-state, bus hold and outputs that can handle forced 5 V. It is compatible with ABT, BCT and FCT-A.

All devices in these families operate from supplies of 1.2–3.6 V. Because of their low dissipation, these devices are eminently suitable for use in battery-operated equipment. Moreover, in view of their high speed, they are also a good choice in fast digital cir-

cuits.

Other advantages are that, because of the low supply voltage, noise levels are down and the reliability of the system increases (because of the lower mechanical stresses in the ICs).

Wide voltage range

Although JEDEC has standardized the supply voltage for mains-operated equipment at 3.3 V \pm 0.3 V, this does not apply to battery-operated equipment. The problem there is the large variation of the battery voltage over the life of the battery. For instance, the e.m.f. of two series-con-

nected alkaline or carbon-zinc batteries at the end of their life is 1.8 V, while that of a NiCd battery is 1.2 V to just before it is fully discharged. Thanks to the wide range of operating voltages of the new devices, the use of dry as well as rechargeable batteries presents no problems.

Low voltage, same speed

As shown in Fig. 1, the speed of a logic component and the supply voltage from which it operates are related. The dynamic power dissipation (the static dissipation of CMOS devices is virtually nil) decreases roughly with the square of a reduction in supply voltage. Thus, an obvious method of reducing the dissipation of these circuits is a decrease of the nominal supply voltage. The relevant graph in Fig. 1 shows that the dissipation of a 3.3-V component is about 65% lower than that of a 5-V component, but is accompanied by a 20% reduction in speed. Thus, the immediate advantages of moving from 5-V to 3.3-V operation are that the speed/dissipation ratio is more than doubled, and it becomes possible to power CMOS logic from a 1-cell or 2-cell battery in portable equipment. The reduction of maximum speed may be negated, and even reversed, by the use of sub-micron technology.

LV-HCMOS family

The LV-CMOS logic family is based on HCMOS (HC) technology and is manufactured in a similar manner. Although developed primarily for operation from 3.3 V supplies, the components in this family can work with supply voltages ranging from 1.0 V to 3.6 V.

With a 3.3 V supply, the speed and performance are the same as HCMOS working from 5 V. There are, therefore, no disadvantages in replacing 5 V logic components with LV-HCMOS devices.

To obtain the same speed as available from 5-V CMOS components, the channel length of LV-HCMOS devices is reduced to 2 μ m, the gate oxide is thinner and the threshold voltages are lowered. Because of the reduced channel length, the propagation delay with a supply of 3.3 V is only 9 ns. With a supply voltage of 2 V, the output drive is 4 mA and even 6 mA for driver outputs. With a 3.3 V supply, outputs can drive loads \geq 130 Ω .

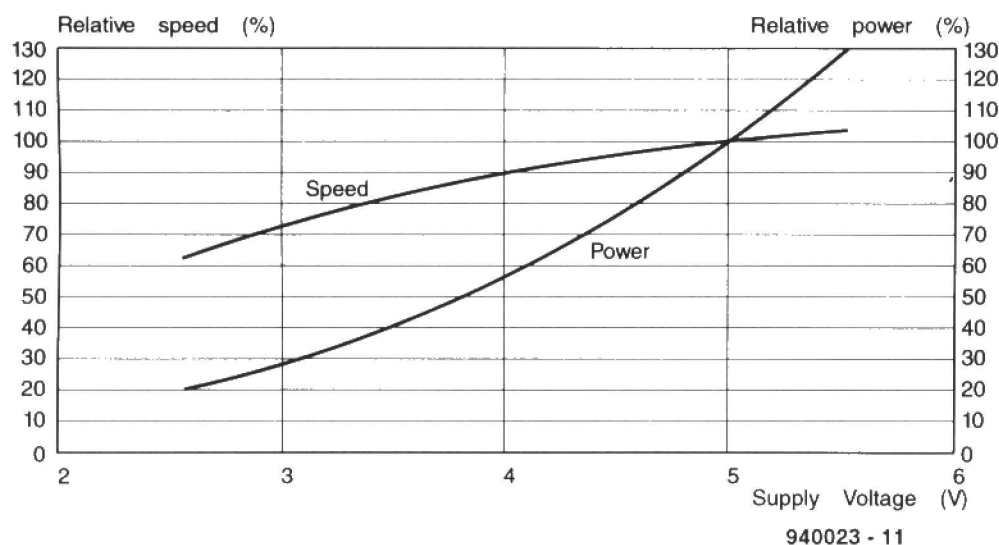


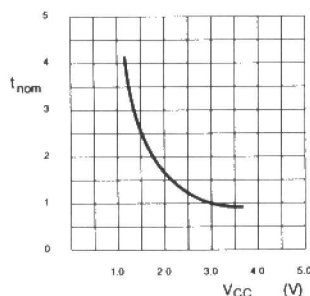
Fig. 1. Relation between supply voltage, speed and dissipation of logic components.

LVC family

The LVC family is compatible with the F(ast) CMOS series as far as speed, output drive characteristics and pinning are concerned. It is manufactured in 6 μm CMOS technology and thus dissipates much less power than F(ast) logic devices. Although designed for operation from a 3.3 V ± 0.3 V supply, the devices can be used with a supply voltage range of 1.2 V to 3.6 V, but they tend to slow down at the lower voltages. With a supply of 2 V, they provide a drive of up to 24 mA. With a 3.3 V supply, outputs can drive loads $\geq 50 \Omega$. Because of the sub-micron technology (0.6 μm), the propagation delay with a supply of 3.3 V is not greater than 6.5 ns. Since, with a supply of 3.3 V, the input levels may be as high as 5.5 V, this family is ideally suitable for use in 5 V to 3 V and 3 V to 5 V level shifting in mixed 3 V/5 V systems.

HLL family

The HLL family is a new logic family: the world's fastest 3.3 V logic ICs. The devices are manufactured in sub-micron (0.6 μm) CMOS technology that uses two-level metal and epitaxial substrates. HLL ICs operating from 3.3 V ± 0.3 V work at twice the speed of F(ast) bipolar logic. Since they are CMOS devices, they dissipate only a fraction of the power needed by bipolar components. The family is ideally suited for very high speed operation in data buses of mains-powered equipment. The sub-micron technology guarantees a propagation delay of not more than 4 ns with a 3.3 V supply. The high dynamic output drive allows transition times to be much shorter than the propagation delay. Outputs can drive loads $\geq 50 \Omega$. With a 3.3 V supply, the devices interface directly with TTL logic.



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Fig. 2. Propagation delay vs supply voltage characteristic.

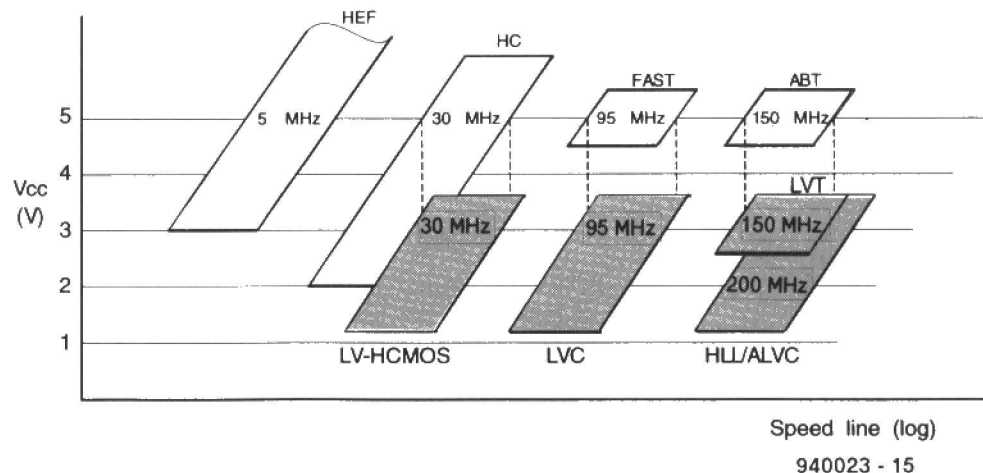


Fig. 3. Each logic family has its own operating area.

Key parameter/feature	LV-HCMOS	LVC	HLL/ALVC	LVT
Key parameters				
Nomenclature*	74LVxxxX	74LVCxxxX	74HLL33xxxX 74ALVC16xxxX	74LVTxxxX
Supply voltage range V	1.0 to 3.6	1.2 to 3.6	1.2 to 3.6	2.7 to 3.6
Output current I_{OH}/I_{OL} mA	6/6	24/24	24/24	32/64
Quiescent current μA	80	20	80/40	80
Typical propagation delay:				
data to output ns	9	4.0	2.1	2.4
output-enable to output ns	14	5.8	4.0	3.6
Max. ground bounce (V_{OLP}) V	0.5	0.8	1.0	0.8
Temperature range $^{\circ}\text{C}$	-40 to +125	-40 to +85	-40 to +85	-40 to +85
Features				
Full CMOS	✓	✓	✓	✓
Advanced BiCMOS				✓
Drive capability:				
135 Ω	✓			
50 Ω		✓	✓	
35 Ω				✓
Effective channel length:				
2.0 μm	✓			
0.8 μm		✓	✓	✓
0.6 μm				
Corner supply pins	✓	✓		✓
Centre supply pins			✓	
TTL level input	✓	✓	✓	✓
TTL level output	✓	✓	✓	✓
5 V input capability		✓**	✓**	✓
Forced 5 V output				✓
Live insertion				✓
Input bus hold				✓
Packages:				
DIL	✓		✓/✓	✓
SO	✓	✓	✓/✓	✓
SSOP	✓	✓	✓/✓	✓
TSSOP	✓	✓	✓/✓	✓
Application:				
glue logic	✓	✓		
battery-powered equipment	✓	✓	✓	
local bus		✓	✓	✓
super μP			✓	✓
backplane				✓
Compatible 5 V families	LS-TTL HC/HCT N74xx	FAST ACL/(Q)FACT ALS	FCT-C	ABT BC/BCT FCT-A
Product differentiator	3 V equivalent of LS/HC	3 V equivalent of FAST	world's fastest logic	3 V equivalent of ABT; optimized for backplanes

* xxx = 245 etc, X = package code: D = SO, DB = SSOP II, PW = TSSOP I, DL=SSOP 48-56, DGG=TSSOP 48-56

** For transceivers $V_{IN\max} = V_{CC} + 0.5 \text{ V}$.

Table 1. Main parameters of the low-voltage CMOS logic families.

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LVT family

The low-voltage BiCMOS logic family is manufactured in 0.8 μm QUBiC technology to combine the best properties of CMOS with

the best of bipolar devices. This results in very high output current and very high speed without compromise of dissipation or noise levels. The outputs can deliver cur-

rents of up to 32 mA and sink currents of up to 64 mA. They can drive loads $\geq 35 \Omega$ directly. The QUBiC technology guarantees propagation delays of not greater

than 4 ns with a supply of 3.3 V. The devices may be used in mixed 3 V/5 V systems.

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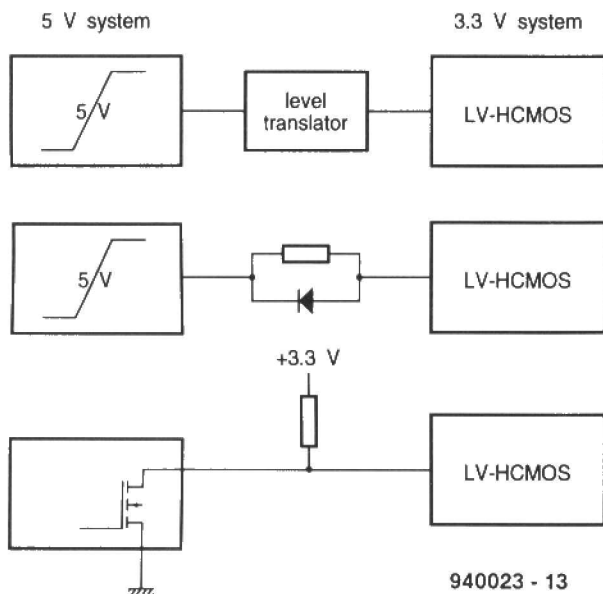


Fig. 4. Various methods of linking traditional 5-V logic devices and low-voltage logic devices.

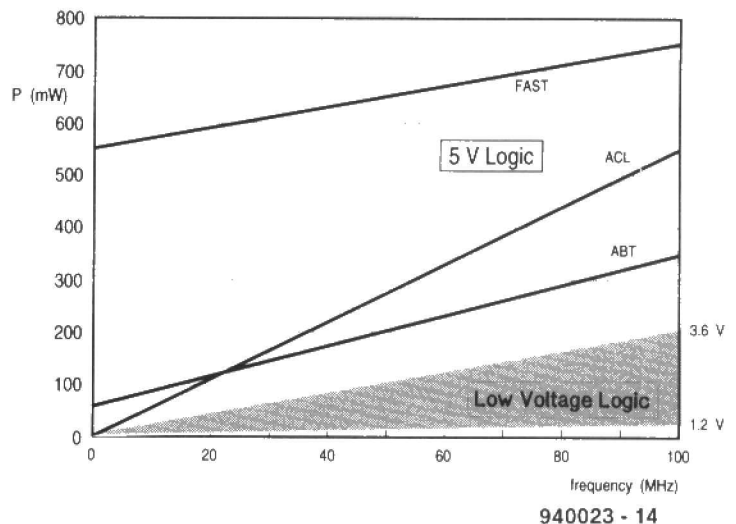


Fig. 5. Dissipation vs frequency characteristics of the various logic families.

MAINS SIGNALLING SYSTEM

PART 2: TRANSMITTER

Design by W. Hackländer & S. Furchtbar

Mains signalling is a method by which signals can be superimposed on mains wiring for the remote control of electrical equipment. It was first proposed by two Swiss inventors, Routin and Brown, who patented the method to control street lighting in 1896. The technique is well established and accepted in the USA, but in this country and Europe interest in it as a medium for communication has begun only in the late 1980s. This article deals with a system for use in home automation. The main advantages of the system are ease of installation, flexibility and relatively low cost (because it uses existing mains wiring).

Since the transmitter is provided with a microprocessor, the command computer need only send simple instructions. These are translated by the transmitter into switching codes for specific receivers. At the same time, the transmitter arranges for the status of each receiver to be sent back to the computer. Communication between the transmitter and computer is via a standard RS232 link.

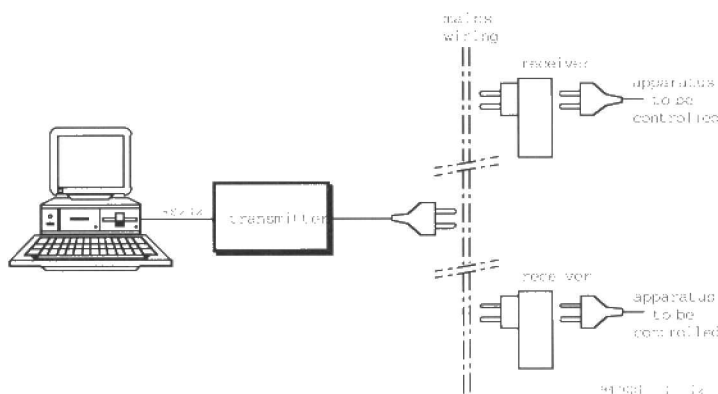
The circuit

Several sections of the circuit—see **Fig. 9**—are identical to parts of the receiver circuit. For instance, modulating and demodulating of the digital signals that are transferred via the mains wiring are again effected by an NE5050. Capacitors C_{15} and C_{16} and transformer Tr_2 form part of a 110 kHz transmit oscillator, whose carrier is switched on and off by the digital signal generated by IC_{7c} . The output signal is supplied via R_{21} and R_{22} to L_1 (which provides harmonics suppression), R_{20} (which provides impedance matching), and C_{12} (which provides d.c. decoupling). From there, the signal is applied to transformer Tr_1 which is linked to the mains wiring via C_{14} . Capacitor C_{13} and the transformer form a band-pass filter with a centre frequency of 110 kHz.

At the demodulating end, the level of the incoming signal (at pin 20) is limited by D_6 and D_7 , which also suppress any spurious signals. In the IC, the signal is applied to an amplifier, to a band-pass filter, Tr_3 - C_6 , a low-pass filter, C_{11} , an AM suppressor, a comparator and a bistable. Finally, it is available at pin 11.

The power supply is conventional: a mains transformer, Tr_4 , bridge rectifier, D_8 - D_{11} , buffer capacitor, C_{18} , and two regulators, IC_{11} and IC_{12} . The first regulator, IC_{11} , provides a direct voltage of 12 V, from which IC_{12} derives a direct voltage of 5 V. Moreover, a direct voltage of 9 V (for the decoder/encoder, IC_1) is provided by R_{11} - D_3 .

Circuit IC_4 is a miniature control sys-



Setup of a 2-receiver system. Up to 127 receivers may be accommodated.

tem with a clock frequency of 12 MHz (derived from crystal X_1).

Circuit IC_5 organizes the addresses on the multiplexed address/data lines PO_0 - PO_7 .

The control program for the transmitter is contained in EPROM IC_6 .

Optoisolators IC_8 and IC_9 connected to pins 10 and 11 of IC_4 effect the communication between the transmitter and computer via the serial interface. They are necessary to ensure proper electrical isolation between the transmitter and equipment connected to the RS232 interface, since transformer Tr_1 does not provide this. Circuit IC_8 passes the data received from the computer to IC_4 , while IC_9 sends data from IC_4 to the computer.

Network D_1 - R_3 at pin 12 of IC_4 serves to indicate confirmation of receipt of data. This interrupt input is controlled by T_1 .

The LED at pin 15 of IC_4 lights during the transmission of data. Output T0 switches NAND gate IC_{7d} via T_2 .

The data for the receivers are sent over lines $P1_0$ - $P1_7$.

Coding and decoding of the receiver addresses are carried out by IC_1 . Network R_1 - C_1 sets the internal clock of this IC to 45 kHz. When the address of a given receiver is sent, the relevant data are available at the P... gates of IC_4 , from where they are applied to IC_1 via buffer IC_3 and level compensator/inverter IC_2 .

Circuit IC_7 and transistors T_1 - T_3 ensure the correct switching sequence during transmitting and receiving. If, for instance, a receiver needs to be switched over, the processor provides the correct address at P1 and, via pin 14, gives the instruction for this address to be sent. Transistor T_2 raises the level from 5 V to 9 V and inverts the signal. The output of IC_{7d} then goes high, whereupon T_3 conducts, so that the output signal of the modem IC is suppressed to prevent IC_1 receiving back its own data during transmission.

NAND gate IC_{7d} sets IC_1 to the transmit mode via its mode input and enables IC_{7b} . The serial data then becoming available at pin 17 of IC_1 are passed via IC_{7b} and IC_{7c} to IC_{10} , where they are modulated and applied to the mains wiring. The code is transmitted several times in succession, which is indicated by the flickering of D_2 , while D_1 lights permanently.

After about 15 seconds, output T0 of the processor goes low, which causes IC_1 to switch from transmit to receive (mode input goes low, IC_{7b} is disabled, and T_3 switches off, so that the signals received by IC_{10} are applied to pin 16 of IC_1). Two addresses monitor whether the slave reacts: that just transmitted and this address plus a '1' in the tenth position, from which the switching status of the receiver

becomes clear.

When, within a given period, a valid address is received four times, pin 17 of IC₁ goes low. This signal is passed to pin 12 of IC₄ via inverter IC_{7a} and level compensator/inverter T₁. This is indicated by D₁ going out. Confirmation of receipt of the data is then given to the computer by IC₄.

Construction

Building the transmitter is simpler than the receiver. All components are housed on a generously sized printed-circuit board, which, for safety's sake, is intended for installation in a man-made fibre enclosure. The use of sockets for the ICs is recommended: this is not only convenient for the construction but also for the cal-

ibration.

Screw the backs of regulators IC₁₁ and IC₁₂ together with in between a U-shaped heat sink. They need not be isolated.

Provide holes in the top of the enclosure for K₂ and the three 5-mm LEDs (for safety's sake, do not use 3-mm types because these may protrude from the enclosure). Provide a hole in one of the shorter

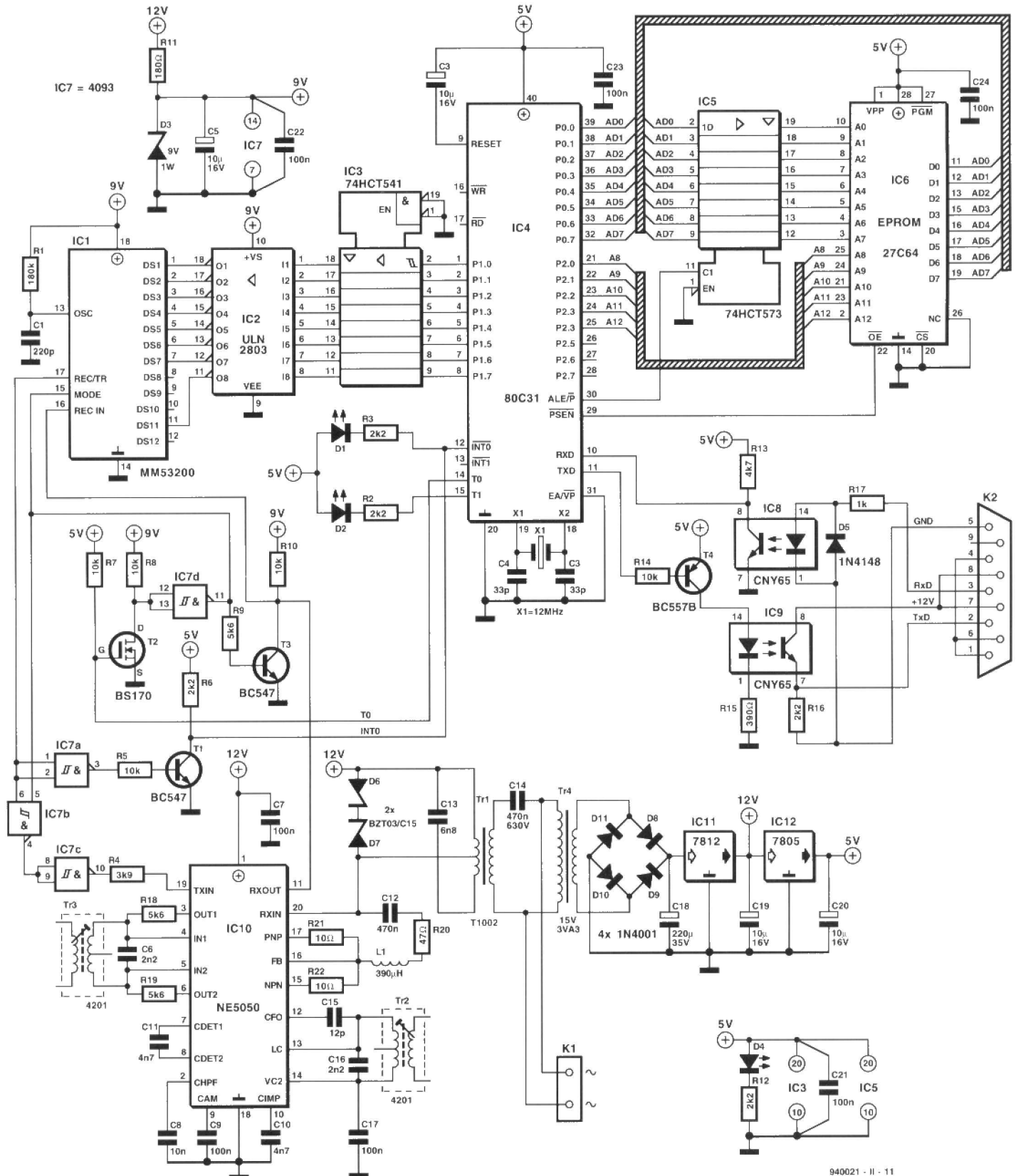


Fig. 9. Circuit diagram of the mains signalling transmitter.

side for mains cable (use a strain relief) entry.

Do not yet place the ICs into their sockets; this should be done during or after calibration.

Calibration

The transmitter and one receiver are required for calibration. Make sure that the ground of the units is connected to the mains earth. Stick insulating tape over all PCB tracks that carry mains voltage to prevent them being touched by acci-

dent. It is better to screw the transmitter board to the bottom inside of the enclosure, which effectively prevents any of the mains-carrying tracks to be touched.

Begin by checking that all supply voltages at the IC sockets are as specified (do not insert the test prods into the socket terminals to prevent these losing their elasticity).

When the voltages are correct, switch off the mains and insert IC₁₀ into its socket. Temporarily interlink pin 19 and pin 1, whereupon a sine wave at an amplitude of about 9 V_{pp} should appear on an os-

cilloscope connected to pin 16. Measure the frequency of this signal with a frequency meter and adjust to 110 kHz by turning the core of Tr₂ with a plastic screwdriver. If a frequency meter is not available, use a long-wave radio receiver (preferably with digital dial). Tune the radio to 330 kHz (3rd harmonic of 110 kHz), place it close to the transmitter (in a position where the 50 Hz mains hum is not or least noticeable) and turn the core of Tr₂ for minimum noise output of the radio. Next, connect the oscilloscope across Tr₁ (at the side with the centre tap) with

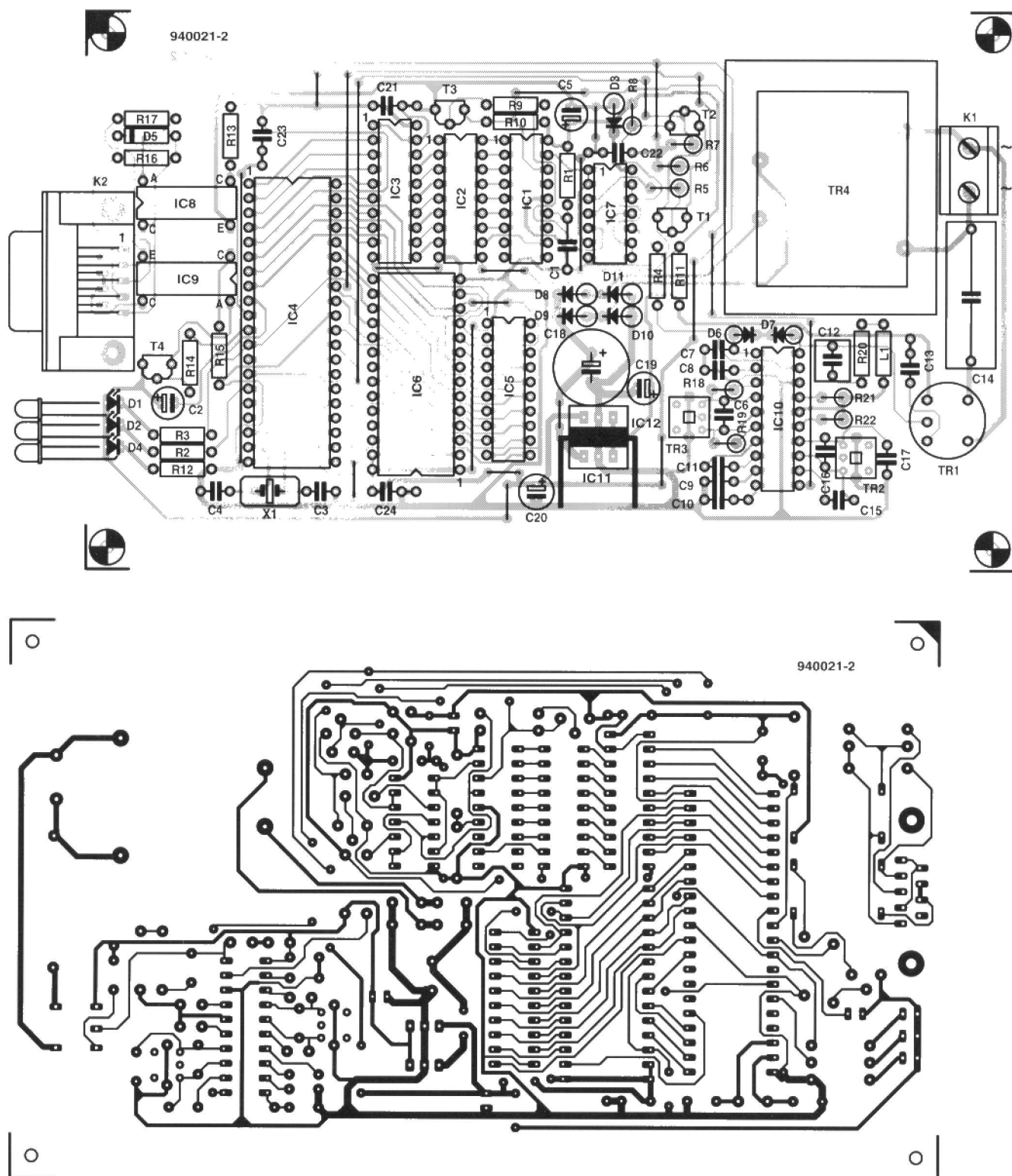


Fig. 10. Printed circuit board of the mains signalling transmitter.

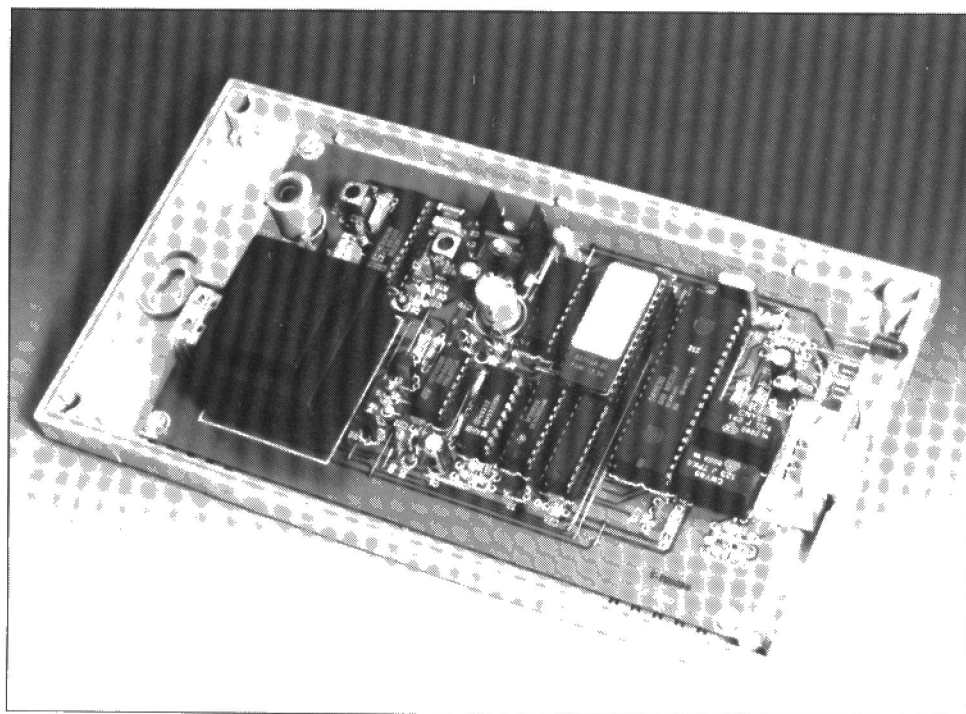


Fig. 11. Completed transmitter before enclosure is closed.

the oscilloscope ground to the +12 V terminal: disconnect the mains earth from the unit earth, since the ground of the oscilloscope is normally also connected to the mains earth. Adjust the core of Tr_1 for maximum signal level on the oscilloscope.

Then, connect the oscilloscope to pin 3 or pin 6 of IC_{10} , where a square wave at an amplitude of about 0.5 V and a d.c. offset of around 4.5 V should be available.

Next, connect the oscilloscope to pin 4 or pin 5, where a sine-wave-like signal with a sort of cross-over distortion should be present. Adjust the core of Tr_3 so that the distortion peaks are symmetrical around the cross-over points. It

will probably not be possible to obtain the same picture at pin 4 as at pin 5, but try to make them as identical as feasible.

Disconnect the link between pin 1 and pin 19 and insert the remaining ICs into their sockets and close the case.

In the receiver, take all ICs from their sockets and check the supply voltages. When these are all correct, insert IC_2 into its socket and carry out exactly the same procedure as just described for IC_{10} in the transmitter.

Insert the other ICs into their sockets.

With the use of jump leads, set the desired address on K_1 : the numbering is binary – no jumper at K_1 gives address 0 and seven jump leads give address 127.

For instance, address 1 (decimal) requires a jump lead on K_1 at the side of pin 1 of IC_5 (call this connection 1); address 100 (decimal), i.e., binary 1100100, needs jumpers on connections 3, 6 and 7. Mark the address on the outside of the case for future reference. Close the case.

Taking into use

Insert the receiver into a mains outlet and connect a mains-operated apparatus to it. At this stage, it is advisable to keep the receiver in sight.

Insert the transmitter into a different mains outlet and connect it to the computer via a serial cable of which all wires are linked 1:1, that is, **not** with the send and receive lines crossed as in a standard serial cable.

Start the program on the computer with the aid of diskette Ref. 1913 (see Parts List). The computer monitor shows an operating panel on which with the mouse or the keyboard (Alt plus underlined character) a COM port may be selected. It is also possible for a relay number to be keyed in, whereupon the software can switch over the relay. The remainder of the procedure is shown on the monitor.

It is also possible to send instructions manually to the transmitter with the aid of a communication program such as Telemate, Unicom or Procomm. The transmitter recognizes the following:

R (52_{hex})—reset transmitter (the program in the transmitter starts from the beginning).

C (43_{hex})—clear status transmitter (only status bits are reset).

T (54_{hex})—switch over the receiver: after the T, the address (0–127) of the relevant receiver must be sent as a byte.

S (53_{hex})—demand status transmitter: in this case, the transmitter sends back a byte containing the following data:

bit 0 – receiver status (0 = relay not actuated; 1 = relay energized). This is valid only if reception was correct.

bits 1–3—**not used**.

bit 4 – syntax error: the command sent by the computer is not recognized.

bit 5 – time out of 20 s: the bit becomes '1' if during this time no answer from the receiver has come in.

bit 6 – busy write: this is high during the period when the transmitter is waiting for an answer from the receiver.

bit 7 – busy read: this high during the period when the transmitter is waiting for an answer from the receiver.

It is, of course, possible for an individual program that uses these commands to be written in, say, Pascal or BASIC.

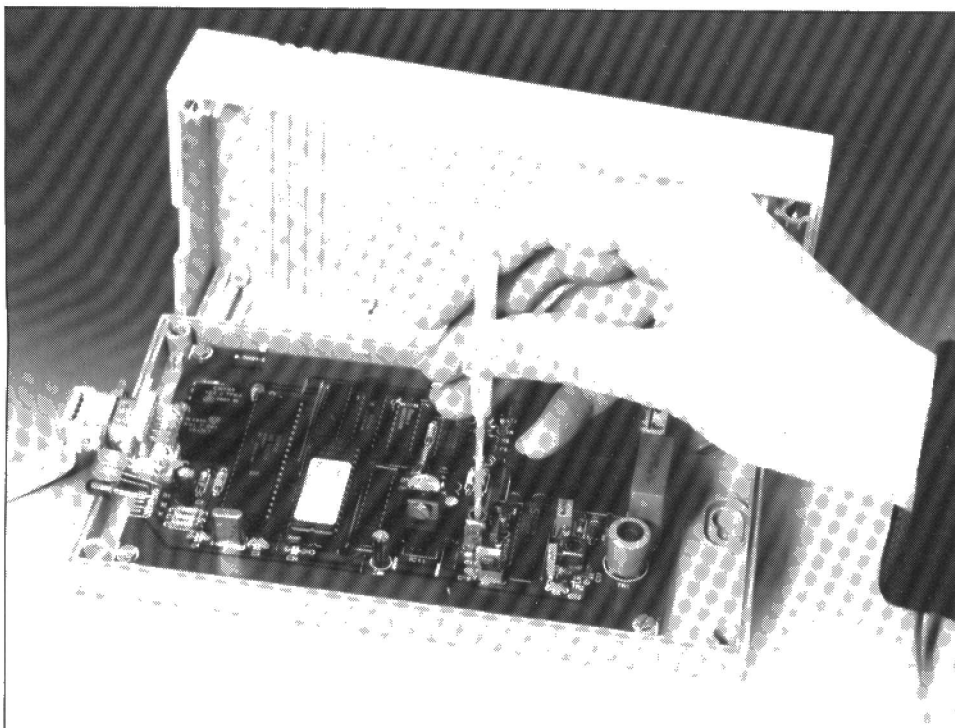


Fig. 12. Take care during the calibration: there is always the risk that open mains voltage is present somewhere on the board.

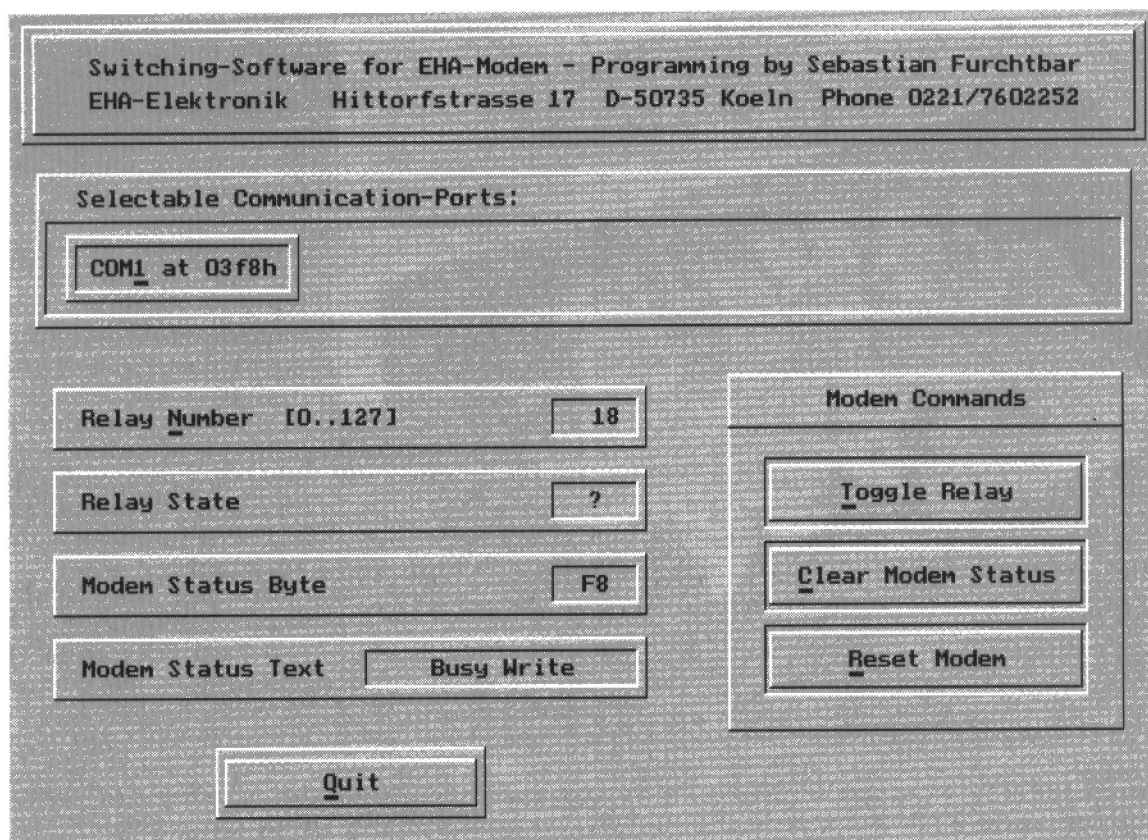


Fig. 13. Control program as seen on the computer monitor.

Parts list

Resistors:

R₁ = 180 kΩ
 R₂, R₃, R₆, R₁₂, R₁₆ = 2.2 kΩ
 R₄ = 3.9 kΩ
 R₅, R₇, R₈, R₁₀, R₁₄ = 10 kΩ
 R₉, R₁₈, R₁₉ = 5.6 kΩ
 R₁₁ = 180 Ω
 R₁₃ = 4.7 kΩ
 R₁₅ = 390 Ω
 R₁₇ = 1 kΩ
 R₂₀ = 47 Ω
 R₂₁, R₂₂ = 10 Ω

Capacitors:

C₁ = 220 pF, polystyrene
 C₂, C₅, C₁₉, C₂₀ = 10 μF, 16 V, radial
 C₃, C₄ = 33 pF
 C₆, C₁₆ = 2.2 nF*, pitch 5 mm
 C₇, C₉, C₁₇, C₂₁-C₂₄ = 100 nF*
 C₈ = 10 nF
 C₁₀, C₁₁ = 4.7 nF
 C₁₂ = 470 nF
 C₁₃ = 6.8 nF*
 C₁₄ = 470 nF, 630 V
 C₁₅ = 12 pF
 C₁₈ = 220 μF, 35 V, radial
 * = polypropylene (MKT)

Inductors:

L₁ = 390 μH

Semiconductors:

D₁ = LED, 5 mm, yellow
 D₂ = LED, 5 mm, green
 D₃ = zener, 9.1 V, 1 W
 D₄ = LED, 5 mm, red
 D₅ = 1N4148

D₆, D₇ = BZT03/C15

D₈-D₁₁ = 1N4001

T₁, T₃ = BC547

T₂ = BS170

T₄ = BC557

Integrated circuits:

IC₁ = MM53200N (National Semiconductor)

IC₂ = ULN2803

IC₃ = 74HCT541

IC₄ = 80C31

IC₅ = 74HCT573

IC₆ = EPROM Ref. 6371 (see p.70)

IC₇ = 4093

IC₈, IC₉ = CNY65

IC₁₀ = NE5050N (Philips/Sigmetics)

IC₁₁ = 7812

IC₁₂ = 7805

Miscellaneous:

K₁ = 2-way terminal block, pitch 7.5 mm

K₂ = 9-pole male D connector, right-angled for PCB mounting

X₁ = crystal, 12 MHz

Tr₁ = transformer T1001

(Toko No. 707VXT1002N)

Tr₂, Tr₃ = transformer 4201

(Toko No. LPCS4201 or LMCS4201) or

4100, 4101, 4102, 4200 or 4202 (also Toko)

Tr₄ = mains transformer, 15 V, 3 VA e.g., Velleman 1150038M (Maplin)

1 off heatsink 27 K W⁻¹ (Fisher Type FK228/SA from Dau, telephone (0243) 553 031)

1 off enclosure 200×112×51 mm (7⁷/₈×4⁷/₁₆×2 in), e.g., Bopla Type EG2050L - in UK represented by Phoenix Mecano Ltd, telephone (0296) 398 853

1 off PCB Ref. 940021-2 (see page 70)

1 off diskette Ref. 1913 (see page 70)

*Further information on the general aspects of mains signalling may be obtained from the BEAMA Interactive and Mains Systems Association, Leicester House, 8 Leicester Street, London WC2H 7BN. Telephone 071 437 0678. Fax 071 437 4901.

In general, for domestic applications, the level of the signal applied across the mains wiring must not exceed 116 dB μV (631 mV). Measured across the line or neutral terminal and ground, the level must not exceed 316 mV (110 dB μV). The specified impedance must be 50 Ω

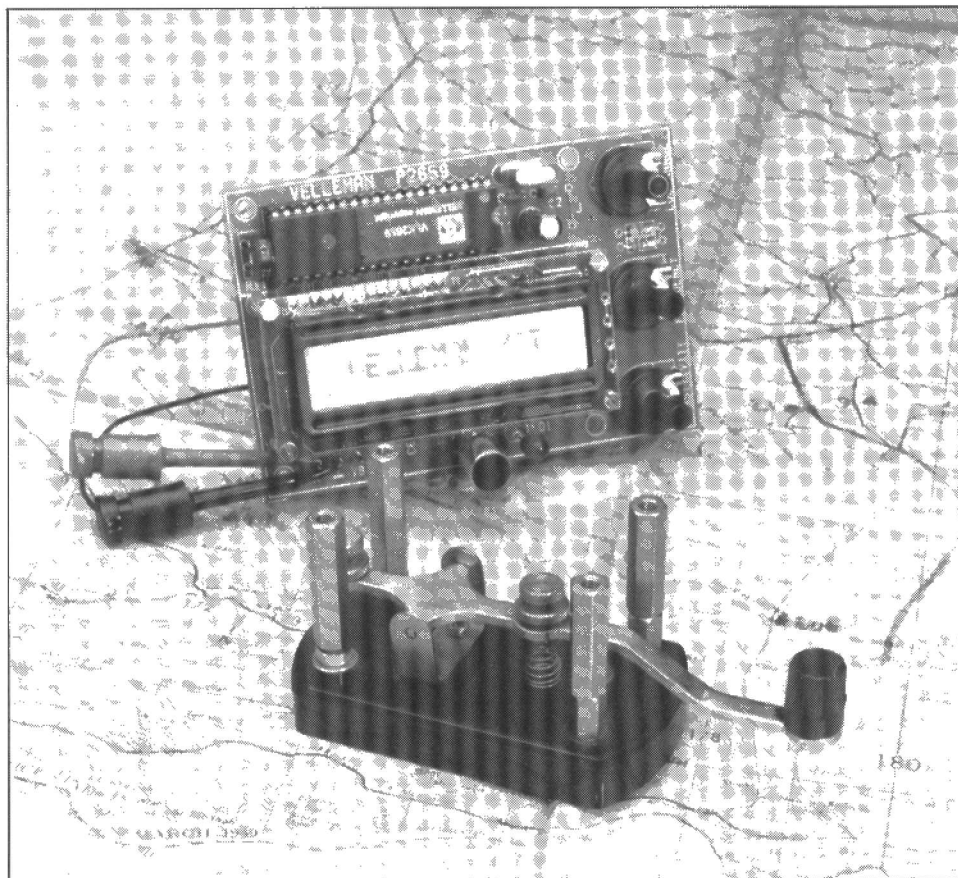
Third harmonic spurious radiations must not exceed 57 dB μV (0.7 mV).

EN 50 065-1 specifies a frequency range of 95-125 kHz.

In practice, these requirements mean that only small energy levels may be applied across the mains wiring. This in turn means that the receiver must be fairly sensitive and that spurious signals and the 50 Hz mains hum must be suppressed adequately. Moreover, as extra precautions, switching instructions must be sent several times, while at the receiver, received codes are compared several times

MORSE DECODER

Some of you may call them hopelessly old-fashioned, but they can still be heard at many frequencies when tuning across the short-wave bands, those unsurpassed long and short tones used to convey messages by radio. Telegraphy, or morse, still exists in the face of the tremendous strides that have been made in modern communication technology. The morse decoder described in this article is available as a kit from Velleman distributors, and enables those cryptic tones from your communication receiver to be deciphered, and turned into text on a liquid crystal display.



Design: © '94 Velleman N.V., Belgium.

MORSE or telegraphy code is a communication method developed at a time when it was impossible to convey speech reliably over large distances using radio links. The morse transmitter is the simplest type of transmitter in existence because basically it is switched on and off by a morse key. Using a relatively simple protocol, the 26 letters in the alphabet, numbers 0 through 9, and a number of punctuation signs, are encoded into a series of short and long tones, which are often called 'dots' (short tones) and 'dashes' (long tones).

Morse transmissions can be re-

ceived in the short-wave and long-wave bands using a communication receiver fitted with a narrow IF (intermediate frequency) filter and a beat frequency oscillator (BFO). To the uninitiated, morse code is just a series of meaningless tones. Experienced morse operators (or 'telegraphists'), however, are capable of copying messages from very weak signals buried under a lot of interference. Meanwhile, they will chat with you, write down the message and smoke a cigarette. This proficiency level and skill is impossible to achieve without training and years of experience. Not surprisingly, many amateurs

prefer the automated solution, for which the present morse decoder is the perfect companion.

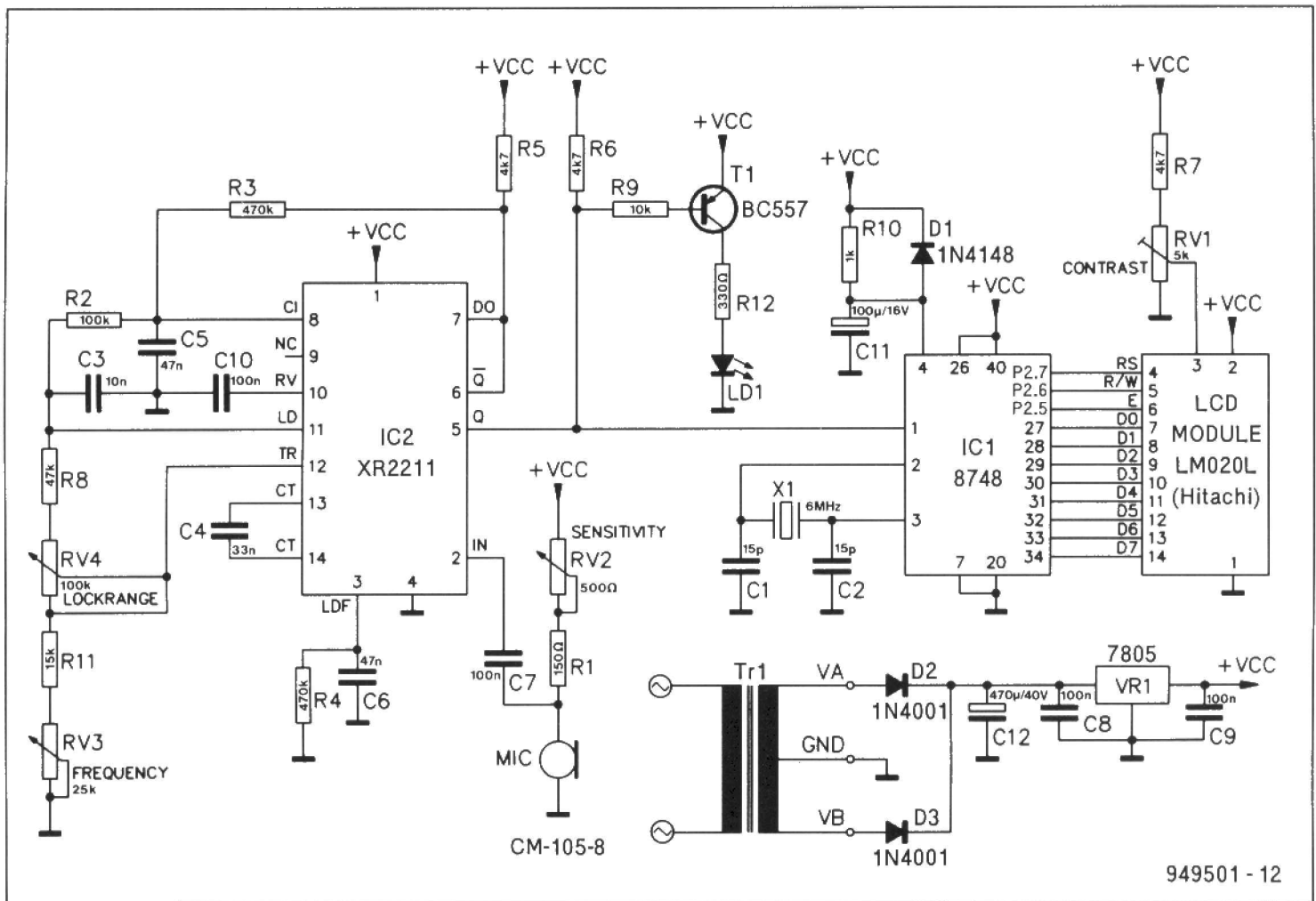
The circuit

The circuit diagram of the morse decoder is given in **Fig. 1**. Broadly speaking, the schematic may be divided into three parts. The circuit around IC₂ turns the morse signal into a digital pulse train. The digital circuit around microcontroller IC₁ turns the digital pulses into text which can be read on a liquid crystal display (LCD). The display used is capable of showing up to 16 characters on one line.

The third section of the circuit is the power supply, which consists of a mains transformer (2×8 V at 150 mA), a double-phase rectifier, and an integrated 5-V regulator. Obviously, the transformer may be replaced by a suitable mains adaptor with an output voltage of between 9 and 12 V.

The input stage of the morse decoder is simple, but effective. The analogue signal picked up by the electret microphone is applied to the input of IC₂ via a coupling capacitor. The XR2211 in position IC₂ is an integrated FSK (frequency-shift keying) demodulator/tone decoder from Exar. As shown by the internal block diagram in **Fig. 2**, this IC contains all components needed to use it as a tone decoder.

The design of a tone decoder should take into account the wide frequency spread of the morse tones. The actual frequency of the morse tones produced by the communication receiver is never fixed because it depends on the exact tuning and, in some cases, the BFO (beat frequency oscillator) setting. Hence, the frequency to which the tone decoder responds is made adjustable. This adjustment is carried out with potentiometers RV₃ (frequency) and RV₄ (lock range). Components C₄, R₁₁ and RV₃ turn the VCO (voltage controlled oscillator) contained in the XR2211 into a variable frequency oscillator. The detector, another sub-circuit of the XR2211, compares the frequency of the oscillator output signal with that of the morse tones picked up by the microphone. Since the frequency of the morse tones can vary considerably, a certain capture range is provided, the span of which is determined by R₈ and RV₄. With the component values shown, the decoder is capable of locking on to frequencies between 77 Hz and 240 Hz with RV₃ set to minimum. This capture range is changed to 550 Hz to 1720 Hz with RV₃ set to



949501-12

Fig. 1. Circuit diagram of the morse decoder, which is available as a kit through Velleman distributors.

maximum. In both cases, the lock range pot, RV_4 , is set to maximum. The adjustment of the two potentiometers can be optimized as soon as a morse transmission is picked up, and the first characters start to appear on the LCD. The two adjustments serve to minimize the decoder's susceptibility to noise, which is unfortunately inherent to radio signals.

The sensitivity of the decoder is adjusted with RV_2 . It is recommended to use the lowest possible sensitivity which allows a good degree of acoustic coupling to be achieved. As with the previously mentioned frequency and lock range adjustments, this helps to keep the distorting effect of noise sources beleaguering the morse signals to a minimum. If desired, R_1 , RV_2 and the microphone may be omitted, and replaced by a simple input stage with a resistor of 47 k Ω to ground. This allows the decoder to be connected directly to the receiver's line output.

The correct operation of the tone decoder may be verified by looking at LED LD_1 . If the LED lights in the rhythm of the morse tones, you may safely assume that the tuning and other adjustments are correct or about correct.

Apart from the LED driver, T_1 , the

morse signals are also applied to the input of microcontroller IC_1 . The controller runs at a clock of 6 MHz, and turns the serial datastream at its input into corresponding parallel codes which can be recognized by the LCD. Preset RV_1 serves to set the LCD contrast for the best legibility/brightness trade-off, which will take you only half a minute or so to find.

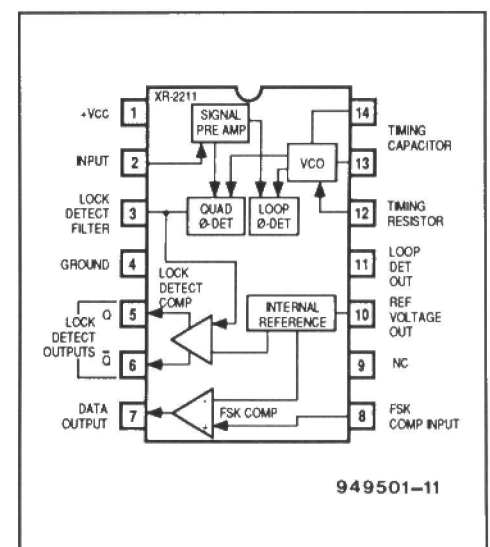
The microcontroller used here is a Type 8748 from Intel's MCS48 family. The 8748 has on-board RAM and ROM. The decoder software is located in ROM, and has been developed by Velleman N.V.

Components R_{10} and C_{11} supply the microcontroller with a reset signal at power-on. Diode D_1 ensures that capacitor C_{11} is discharged rapidly when the circuit is switched off. Capacitor C_{11} has a value of 10 μ F in the kit supplied by Velleman. Based on practical experience, we recommend changing this into 100 μ F to ensure a more reliable reset.

Construction

Assembling the decoder is easy using the components and the printed circuit board contained in the kit. The

track layout and component mounting plan of the printed circuit board designed for the morse decoder are shown in Fig. 3. Construction is straightforward, and no problems are expected to arise if you work carefully. The LC display module is fitted on to



949501-11

Fig. 2. Internal organization of the XR2211 FSK demodulator/tone decoder (courtesy Exar).

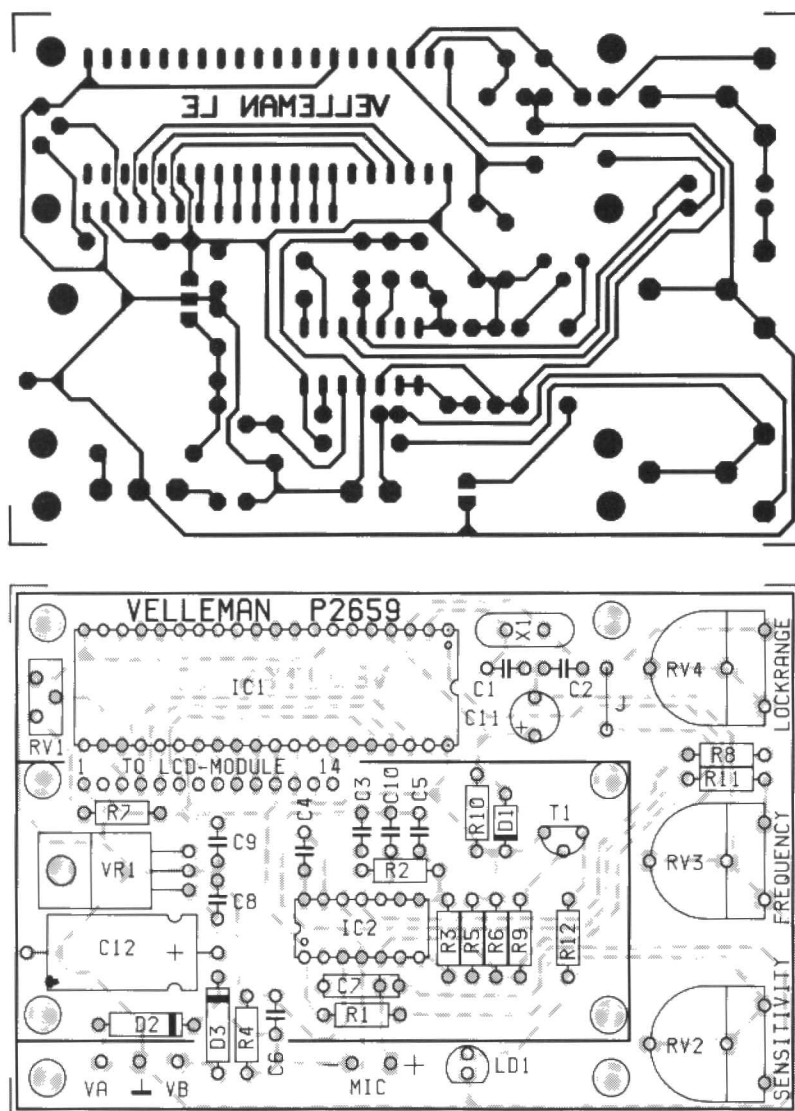


Fig. 3. Track layout (reflected) and component mounting plan of the single-sided PCB included in the kit.

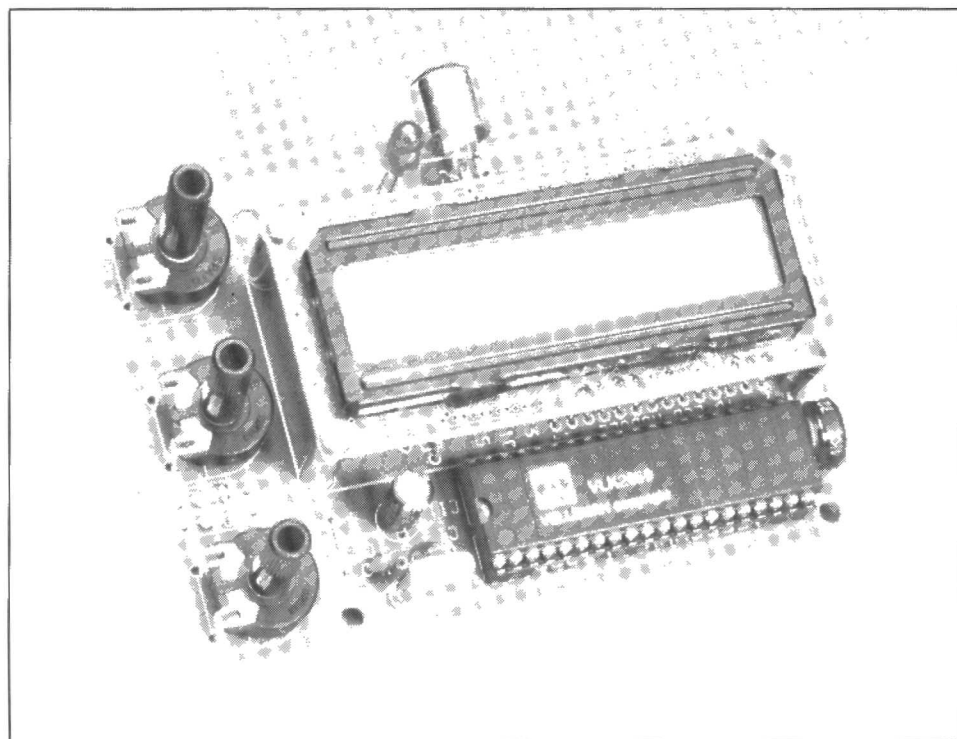


Fig. 4. Completed morse decoder. If desired, the unit may be built into a suitable case.

COMPONENTS LIST

Resistors:

R1 = 150Ω
 R2 = 100kΩ
 R3, R4 = 470kΩ
 R5, R6, R7 = 4kΩ
 R8 = 47kΩ
 R9 = 10kΩ
 R10 = 1kΩ
 R11 = 15kΩ
 R12 = 330Ω
 RV1 = 5kΩ preset
 RV2 = 500Ω preset
 RV3 = 25kΩ preset
 RV4 = 100kΩ preset

Capacitors:

C1, C2 = 15pF
 C3 = 10nF
 C4 = 33nF
 C5, C6 = 47nF
 C7, C8, C9, C10 = 100nF
 C11 = 100μF 16V
 C12 = 470μF 16V

Semiconductors:

IC1 = programmed 8748 (supplied by Velleman; order no. VK2659)
 IC2 = XR2211
 VR1 = 7805
 T1 = BC557
 D1 = 1N4148
 D2, D3 = 1N4001
 LD1 = LED red

Miscellaneous:

Mic = M300 or CM-105-8.
 X1 = quartz crystal 6MHz
 Tr1 = 2x9V/4.2VA (e.g. Velleman 2090050M).
 One 1-line, 16-character LCD module, HLM1615 or Hitachi LM020L.

Kits for the morse decoder are available from

Maplin Electronics, P.O. Box 3,
 Rayleigh, Essex SS6 2BR. Tel. (0702) 554161, fax (0702) 553935.

Circuit Distribution Ltd., Park Lane,
 Broxbourne, Herts EN10 7NQ. Tel.: (0992) 444111, fax (0992) 464457.

the board with the aid of four PCB pillars. This is done after all other parts have been mounted on the board. The display is connected to the board via short lengths of flexible wire. Insert the spindles into the three presets on the board, and connect the microphone via a short length of screened wire, so that it can be mounted close to the receiver's loudspeaker.

Apply power, and check that the dis-

Morse, a simple code

The morse or telegraphy code was developed to convey messages over radio and telegraph wire links with a very limited bandwidth. Apart from the complete alphabet, the code set also includes numbers and a couple of punctuation signs. The complete morse alphabet was developed by Samuel Morse, who lived from 1791 to 1872. This American is also the inventor of the writing telegraph (1837). All morse codes are a combination of two elementary characters: a dot (.) and a dash (—). The dot has a length of one time unit, the dash, a length of three units. The length of the pause between a dot and a dash, but also between a dot and a dot, and a dash and a dash, is fixed at one unit. The length of the pause between letters, numbers or signs equals three units. Similarly, the pause between words or number groups equals six (or seven) time units. The actual length (say, in ms) of the time unit is not defined, and is merely a relative indicator of the transmission speed. In most cases, however, a time unit is simply equal to a dot.

Letters

A	•—
B	—•••
C	—•—•
D	—••
E	•
F	••—•
G	—•—•
H	••••
I	••
J	•—•—
K	—•—•
L	•—••
M	—•—
N	—•
O	—•—•
P	•—•—•
Q	—•—•—
R	•—••
S	••••
T	—
U	••—
V	•••—
W	•—•—
X	—••—
Y	—•—•—
Z	—•—••

Numbers

1	•—•—•—
2	••—•—•—
3	•••—•—•—
4	••••—•—
5	•••••
6	—••••
7	—•—•••
8	—•—•—••
9	—•—•—•—•
0	—•—•—•—•—

Punctuation signs

-	—••••—
?	••—••••
(—•—•—•
)	—•—•—•—
,	•—••—•—
“	—••••—•—
’	•—•••—•—
=	—•••—•—
/	—•••••
+	•—••••
:	—•—••••
x	—•••—

Special codes

Warning	•—•••—
Error	••••••••
Repeat	•••••
Wait (AS)	•—••••
Break (BK)	—••••—•—
Copied (VE)	••••—•
Transmission received (R)	•—•
Start of message (KA)	—•—•—
End of message (AR)	•—••—•
End of transmission (K)	—•—
End of transmission (KN)	—•—•—•
Closing sign (SK)	••••—•—
Transmitter closedown (CL)	—•—•••—•



Fig. 5. The morse decoder in action. Any morse signal can be picked from the 'aether', decoded into text, and thrown on to a scrolling LC display for you to read.

time (in most cases, that will be a utility station, not a radio amateur).

Next, switch on the morse decoder. After the test message 'Velleman kit', the decoded text should scroll along horizontally across the display. Using the LED as an indicator, the best possible adjustment of the tone frequency and the lock range will soon be found. Reduce the receiver volume, or the decoder sensitivity, if the LED appears to light continuously, since that indicates that the circuit is being overdriven. If the LED is nearly always out, the microphone does not pick up enough signal, and the acoustic coupling should be examined. ■

play reads 'Velleman kit'. This indicates that the hardware is operational. Switch off again.

Adjustment

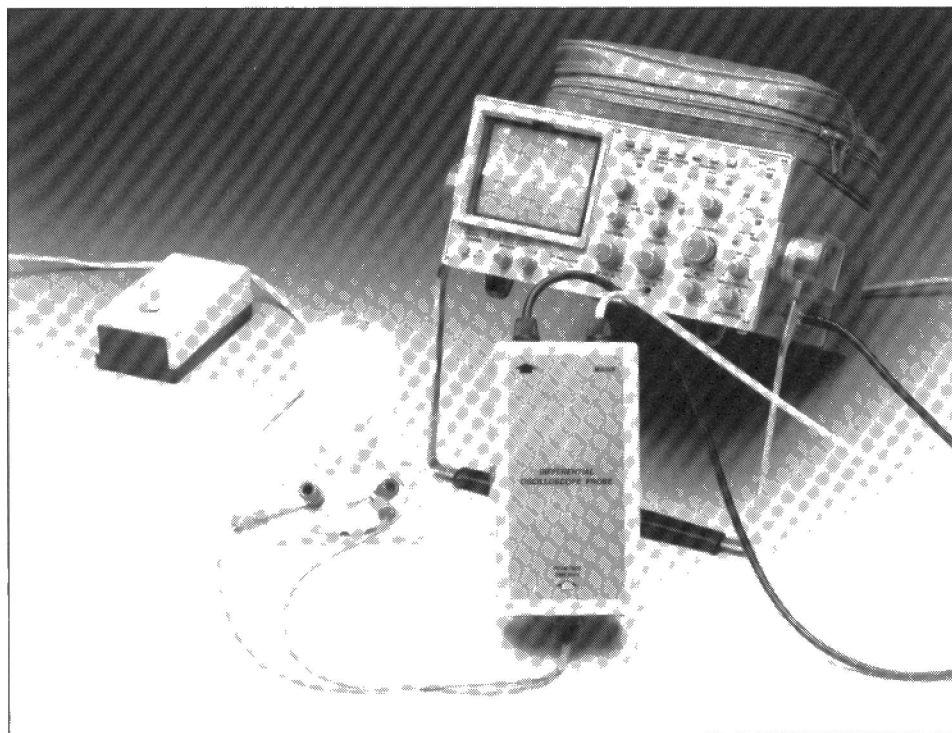
Before you can start adjusting the various controls on the morse decoder, it is necessary to tune to a strong, clear, morse transmission. In many cases, these can be picked up from Coast Guard and similar utility stations transmitting at countless frequencies

across the short-wave bands. The prototype of the kit assembled in our design laboratory was tested with the morse signals received from Scheveningen Radio (PCH20) coast guard on 4,250 kHz. Set the receiver to CW mode, or SSB using the BFO, and adjust the tuning until the morse tones sound as clear as possible. Some background noise is normal and no cause for alarm. In any case, make sure you use a good antenna, and select a station which remains on the air for some

DIFFERENTIAL PROBE FOR OSCILLOSCOPES

Design by H. Bonekamp

The probe described overcomes several of the shortcomings of the probe supplied with many oscilloscopes. It is a 10:1/100:1 design that enables floating measurements to be carried out. Its presettable attenuation to 10 V or 100 V and its facility for floating measurements makes it also suitable for measuring high voltages.



When the resistive or capacitive load connected to many oscilloscopes is too large, serious measurement errors may occur. Moreover, the voltage range on many oscilloscopes is limited to 5 V graticules, so that the maximum voltage that can be measured is 40 V. This is, of course, improved by the supplied 10:1 probe to 400 V, but even this is inadequate for many applications. Another problem with a number of oscilloscopes is created by the external (mains) earth being permanently connected to the ground of the instrument. Since, moreover, the equipment on which measurements are carried out is often also connected to the mains earth, a potentially dangerous situation may arise when very high voltages are measured. This also means that measurements are always referred to earth: in mains-operated apparatus it is virtually impossible to measure the potential between two random points.

Differential measurements

Measurements **not** referred to earth can be made only by using a differential probe. Such a probe has two prods, each of which 'floats' with respect to earth. An accurate differential amplifier/buffer ensures that

the probe is provided with the true potential difference between the prods. Differential probes with presettable attenuator are commercially available, but tend to be fairly expensive. The present probe is considerably less so.

Since the probe must not noticeably load the equipment on test, its input resistance is high and its input capacitance low. Moreover, the input is frequency compensated to ensure that linear performance is obtained over a wide frequency range. The attenuator networks for each prod are as nearly equal as possible. Moreover, the common-mode suppression is high.

The circuit

The circuit—see **Fig. 1**—is based on special dual differential amplifier IC₁. This is a wide-band device that provides accurate processing of a differential input signal. Moreover, it attenuates common-mode signals up to very high frequencies. Basically, it consists of two separate differential amplifiers followed by a common buffer. Pins 1 and 2 respectively form the +ve and -ve inputs of one and pins 3 and 4 those of the other. The common output is available at pin 7. Feedback network R₁₀-R₁₁ fixes the amplification at ×2. The potential divider at pin 4 ensures accurate compensation of the d.c. offset (owing to the offset current, the value of R₉ is equal to that of R₁₀ and R₁₁ in parallel).

The attenuator networks are situated between IC₁ and connector K₁ (to which the test prods are connected). They consist of precision resistors R₁-R₇. Frequency compensation is provided by capacitors C₁-C₈. With values as specified, the input resistance is about 2 MΩ and the input capacitance around 2.5 pF. Moreover, the specified values ensure that the time constants in the probe are determined by the actual components rather than by parasitic effects.

Since for good common-mode suppression equality of the networks is imperative, one has a fixed 10-Ω resistor (R₄), whereas the corresponding (20-Ω) resistance in the other is variable (P₁). This arrangement makes it possible for any measurement error to be nullified.

PARAMETERS

Attenuation	100:1 or 10:1
R _{in}	2 MΩ (approx)
C _{in}	<2.5 pF (without test leads)
U _{in} (differential)	450 V peak; 450 V r.m.s.
U _{in} (common mode)	700 V peak; 500 V r.m.s.
Bandwidth	20 MHz (100:1) 15 MHz (10:1)
CMRR	80 dB (up to 100 kHz) 60 dB (up to 1 MHz) 40 dB (up to 10 MHz)
Accuracy (see text)	0.6% max (100:1)

Moreover, variable capacitors C_4 and C_8 enable equality of the networks to be achieved at high frequencies.

Although the wanted maximum attenuation factor is 100:1, the input attenuator is set to 200:1. This is to keep the differential input voltage of IC₁ within limits: the AD830 has internal limiting that comes into operation when the level of the differential signal reaches 2.3 V. As the amplification of the device is $\times 2$, the final attenuation is 100:1.

Because of the internal limiting in IC₁, it is not possible to switch the input attenuator to 10:1 without degradation of the common-mode suppression. This is resolved by adding amplifier IC₂. The amplification of this stage can be switched between 1 and 10, so that the attenuation can be switched between 10:1 and 100:1. So as to affect the bandwidth of IC₂ as little as possible, the input resistance, rather than the feedback resistance, is switched (by S_1) between 1 k Ω (R_{12}) and 100 Ω (R_{11} in parallel with R_{13}).

The output impedance of the probe is

50 Ω (R_{15}) to ensure good matching to RG58 coaxial cable.

The operating voltage for the probe is provided by a standard supply. The two power lines are stabilized by regulators IC₃ and IC₄. Each rectifier diode is shunted by a capacitor to eliminate any spurious signals. Diode D_1 functions as an on/off indicator.

Note that each of the ICs is individually decoupled for r.f. by C_{17} - C_{18} and C_{19} - C_{20} respectively: this measure is necessary with fast devices.

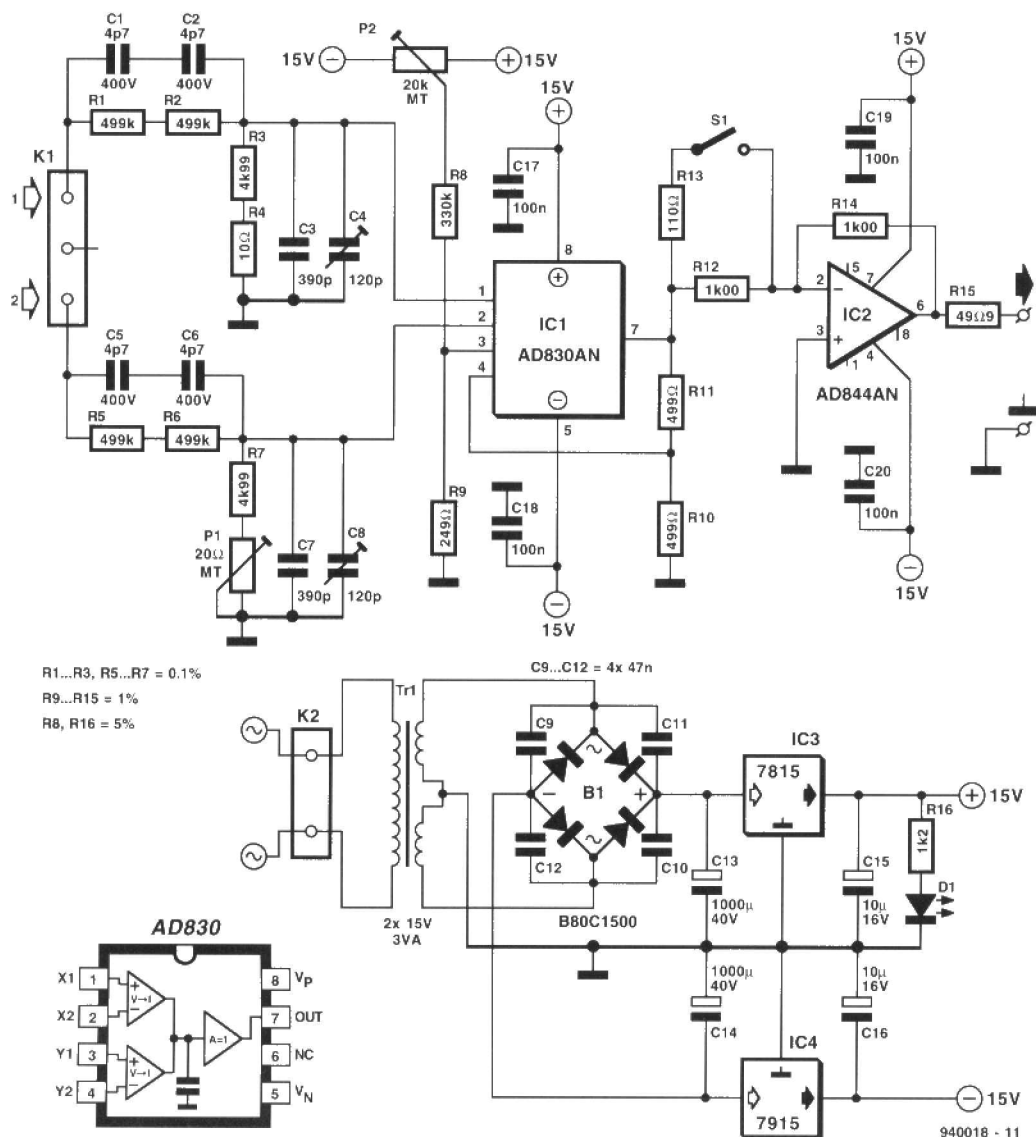
As already stated, attenuator resistors R_1 - R_7 are close-tolerance (0.1%) types, whereas R_9 - R_{14} are precision (1%) types. This gives an overall measurement accuracy of 4.2%, which is an acceptable practical value. If maximum accuracy (0.6% in the 100:1 position and 1.6% in the 10:1 position) is required, R_9 - R_{14} must also be 0.1% types. If 0.1% resistors can not be obtained, R_1 - R_7 may be 1% types, but the value of R_4 and P_1 must then be increased to 100 Ω and 200 Ω respectively. This not only degrades the mea-

surement accuracy, but may also affect the equality of the networks adversely and reduce the common-mode attenuation.

Construction

The probe, including its power supply, is best built on the printed-circuit board shown in **Fig. 2**. Because of the high signal frequencies likely to be encountered, mount the ICs directly on to the board: do not use sockets. A number of components must be soldered at both sides of the board. Since, for safety's sake, conductors carrying high voltages must be separated by ≥ 6 mm, remove the centre terminal of terminal block K_1 . Mount S_1 directly on to the board and solder its metal case to earth.

When all components have been fitted, three tin plate screens have to be installed: one around each of the attenuator networks and one around the active circuits. These screens are shown in **Fig. 2** and **Fig. 3**. They must be about 15 mm high and be provided with holes for ad-



justing C_4 , C_8 , P_1 and P_2 , as well as for accepting the spindle of S_1 . Solder them to pins placed in suitable positions on the board. Make sure that the distance between components and screens is not less than 6 mm. Cover the compartments so formed with a tin plate lid soldered in place.

Fit a tin plate screen (of which the edges have been bent at right angles) over the track side of the board. Cover the inside of this lid with a sheet of thin polythene to ensure that the screen does not short circuit any of the tracks or solder pads.

The board is intended to be fitted in an man-made fibre enclosure of 150×80×55 mm ($6 \times 3 \frac{1}{8} \times 2 \frac{3}{16}$ in). The enclosure may be finished at the front and side as shown in Fig. 4.

Connect the prods to terminal block K_1 via 30 cm lengths of flexible multi-strand cable. Connect the probe to the oscilloscope via a 60 cm length of RG58 coaxial cable. Terminate this cable at one end into a BNC connector and solder the other end to pins PC1 and PC2 on the PCB.

Calibration

Calibration must be carried out with S_1 in position 10:1. It is advisable to let the probe warm up for about 15 minutes before starting the calibration.

Short-circuit both input terminals to earth. Connect the probe output to an oscilloscope or millivoltmeter set to its most sensitive d.c. range. Adjust P_2 until the d.c. (**off-set**) measured is zero.

Interlink the input terminals and apply a direct voltage or low-frequency voltage between this link and earth. Connect the probe output to an oscilloscope or millivoltmeter set to its most sensitive d.c. range. Adjust P_1 for zero reading. This sets the **common-mode rejection ratio** (CMRR) at low frequencies.

Connect a 1 kHz square wave signal between input 1 and earth. Connect the output of the probe to an oscilloscope. Adjust C_4 until the oscilloscope shows a neat square wave. Then do the same at input 2. This sets the **frequency compensation**.

Interlink the input terminals and con-

nect the probe output to an oscilloscope. Inject a 1 MHz sine wave signal between the linked inputs and earth. Carefully adjust C_4 and C_8 in turn until the amplitude of the signal on the oscilloscope is as small as feasible. This sets the **com-**

mon-mode rejection ratio at high frequencies. Check the setting of the frequency compensation.

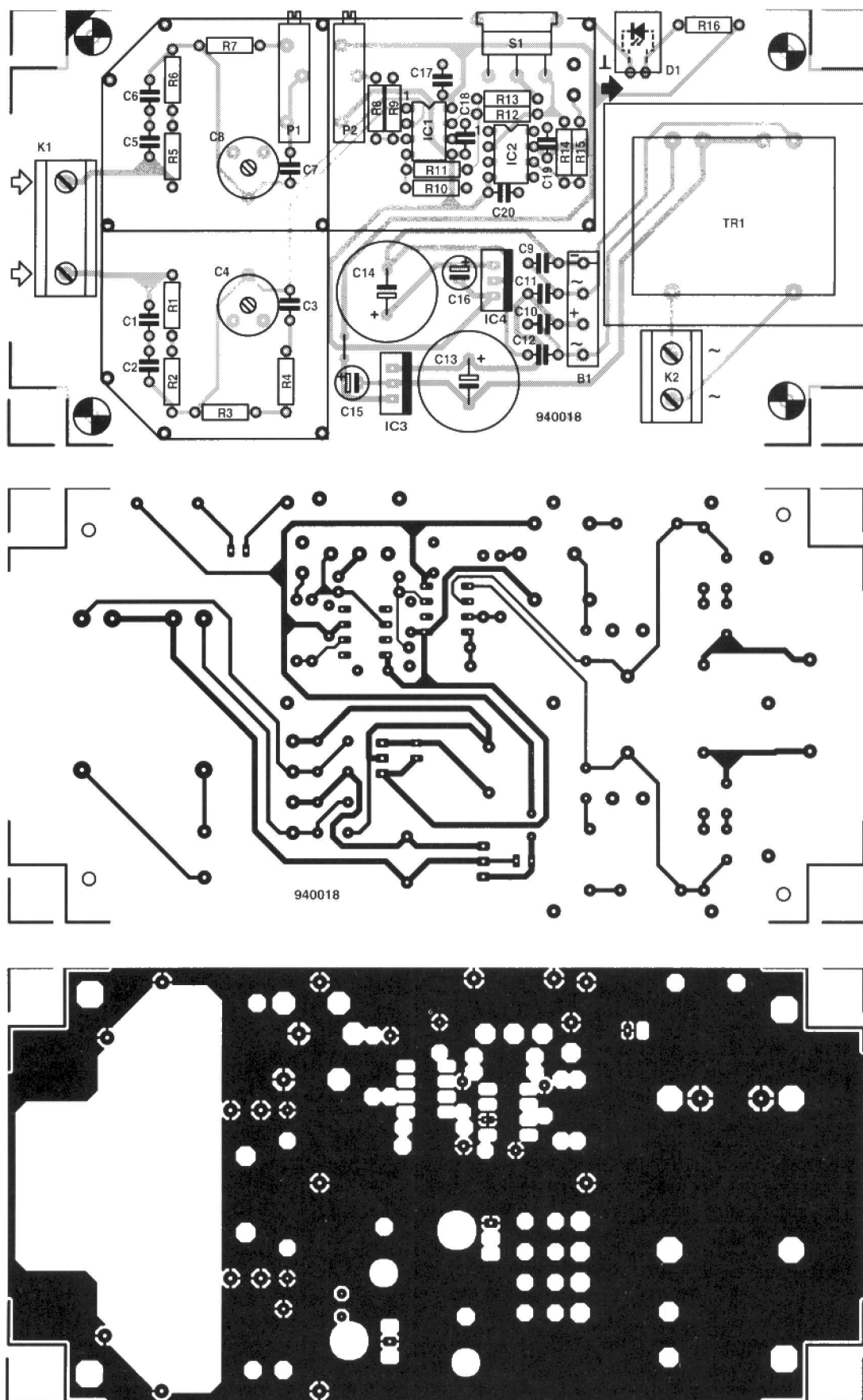


Fig. 2. Printed-circuit board for the differential probe for oscilloscopes.

Parts list

Resistors:

$R_1, R_2, R_5, R_6 = 499 \text{ k}\Omega, 0.1\%$
 $R_3, R_7 = 4.99 \text{ k}\Omega, 0.1\%$
 $R_4 = 10 \Omega, 1\%$
 $R_8 = 330 \text{ k}\Omega, 5\%$
 $R_9 = 249 \Omega, 1\%$
 $R_{10}, R_{11} = 499 \Omega, 1\%$
 $R_{12}, R_{14} = 1.00 \text{ k}\Omega, 1\%$
 $R_{13} = 110 \Omega, 1\%$
 $R_{15} = 49.9 \Omega, 1\%$
 $R_{16} = 1.2 \text{ k}\Omega, 5\%$
 $P_1 = 20 \Omega$ multiturn preset
 $P_2 = 20 \text{ k}\Omega$ multiturn preset

Capacitors:

$C_1, C_2, C_5, C_6 = 4.7 \text{ pF}, 400 \text{ V, ceramic}$
 $C_3, C_7 = 390 \text{ pF, ceramic}$
 $C_4, C_8 = 120 \text{ pF trimmer}$
 $C_9\text{--}C_{12} = 47 \text{ nF}$
 $C_{13}, C_{14} = 100 \mu\text{F}, 40 \text{ V, radial}$
 $C_{15}, C_{16} = 10 \mu\text{F}, 16 \text{ V, radial}$
 $C_{17}\text{--}C_{20} = 100 \text{ nF}$

Semiconductors:

$B_1 = \text{B80C1500}$
 $D_1 = \text{LED}, 5 \text{ mm, red}$

Integrated circuits:

$\text{IC}_1 = \text{AD830AN}$
 $\text{IC}_2 = \text{AD844AN}$
 $\text{IC}_3 = 7815$
 $\text{IC}_4 = 7915$

Miscellaneous:

$K_1 = 3\text{-way terminal block, pitch } 5 \text{ mm}$
 (remove centre terminal)
 $K_2 = 2\text{-way terminal block, pitch } 7.5 \text{ mm}$
 $S_1 = \text{single-pole slide switch}$
 $\text{PC}_1, \text{PC}_2 = \text{solder pin}$
 $\text{Tr}_1 = \text{mains transformer, } 2 \times 15 \text{ V, } 3 \text{ VA}$
 Enclosure $150 \times 80 \times 55 \text{ mm}$
 ($6 \times 3 \frac{1}{8} \times 2 \frac{3}{16} \text{ in}$)
 (for instance Bopla Type E440BB—in
 UK available from Phoenix Mecano,
 telephone 0296 398 853)
 PCB Ref.940018

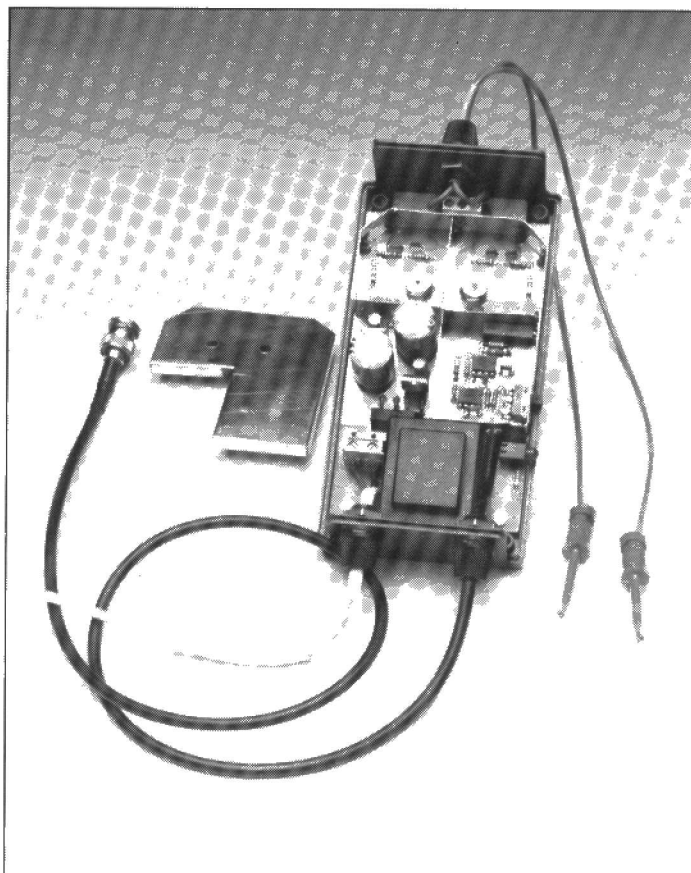


Fig. 3. Completed prototype with lid removed; note the three screened boxes.

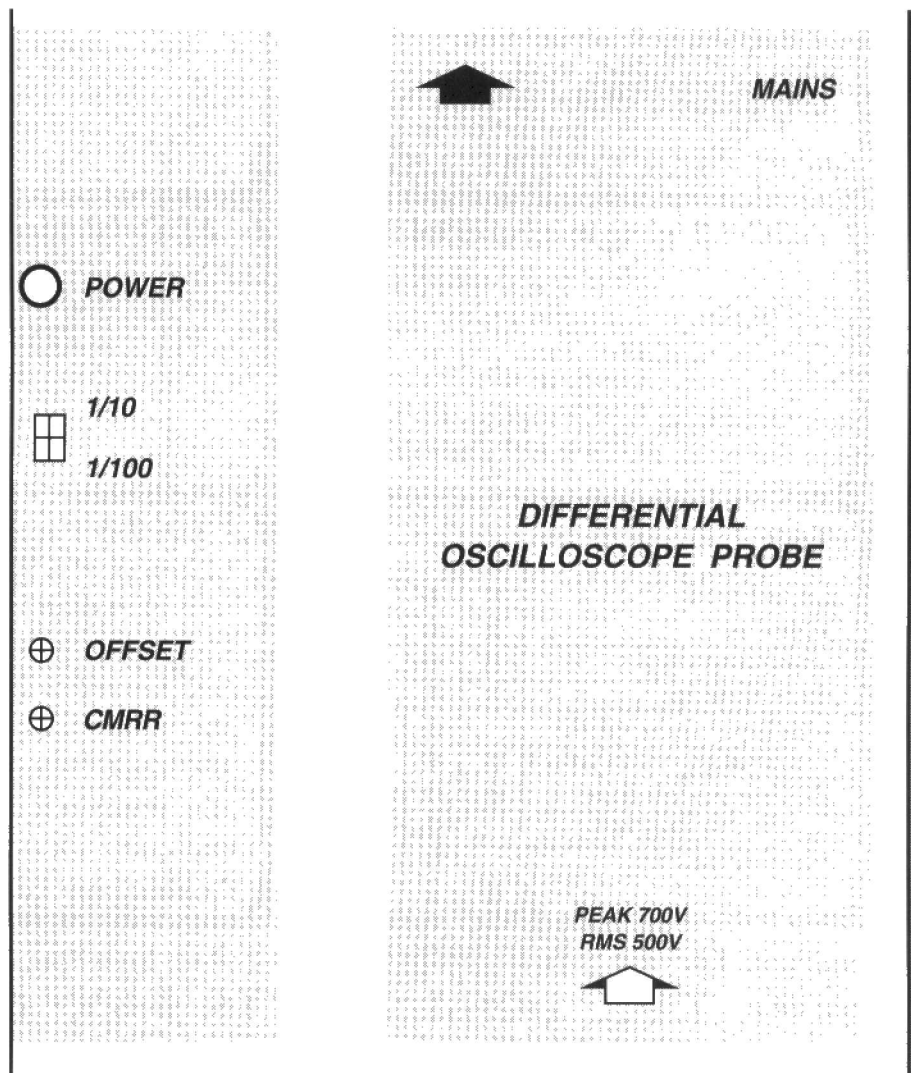
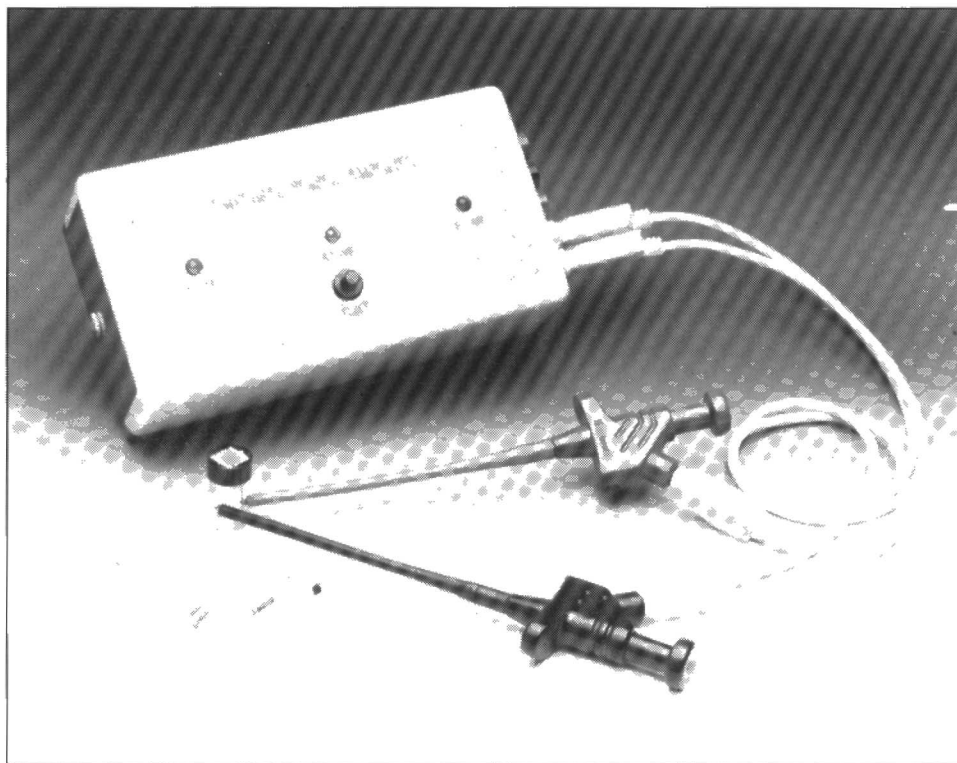


Fig. 4. Suggested side and front panel marking (not available ready made).

GENERAL PURPOSE SENSOR MONITOR



Sensors and transducers are interesting electronic devices to work with, but the snag is that their output signal invariably requires a made-to-measure amplifier that enables an indicator circuit to be driven. LDRs, temperature sensors, strain gauges, they all need an amplifier with very specific characteristics. The amplifier described here is designed to handle almost any sensor signal, has adjustable switching thresholds, and will be invaluable for quick experiments with a wide variety of sensors, both polarized and unpolarized.

Design by M. Haas

THE heart of the circuit shown in **Fig. 1** is formed by the trusty 741 opamp, IC₄. Here, the 741 is wired as a comparator with hysteresis. The sensor voltage arrives at the non-inverting input, pin 3, via a low-pass filter, R₄-C₃, which serves to suppress fast signal variations. The inverting input of the opamp, pin 2, is held at a reference level which is adjustable with preset P₁. As long as the voltage on pin 3 is lower than that on pin 2, the output of

the 741, pin 6, will remain low (approx. 0 V). The output swings high (to about 10 V) if the voltage on pin 3 is higher than that on pin 2.

Hysteresis is introduced by R₇ and P₂ which feed a small portion of the output voltage back to the input. The opamp output voltage is fed to two NAND Schmitt trigger gates, IC_{1c} and IC_{1d}, via low-pass filter R₈-C₅. The two gates are inverters, and allow a single jumper to select between a relay which

is normally energized or normally off. The choice between jumper A or B depends on the comparator's output level under normal conditions, and, thus, on the type of sensor used.

The relay is driven by transistor T₁ via resistor R₉. LED D₂ gives an extra indication of the current relay state (on or off). Since the relay coil current is greater than the maximum permissible current through the LED, the two devices can not be connected in series just like that. Shunt resistor R₁₀ prevents a too high voltage across the LED (i.e., too much current through the device).

The relay contacts are brought out to pins on connector K₂. The pin marked 'P' is the pole, while 'NO' and 'NC' mark the normally open and normally closed contact respectively.

Although the contacts of the relay mentioned in the parts list are, in principle, capable of switching the mains voltage, that should not be attempted for the sake of safety. If you still wish to switch mains operated loads, mount the relay off the board, in a separate, ABS, enclosure. For the sake of safety, use grommets and strain reliefs for the mains wiring, and isolate the relay pins with heat-shrink sleeving.

Bistable

The output signal of the comparator is also used to clock a D-type bistable, IC_{2b}. Because the D (data) input of the bistable (pin 9) is tied permanently to the +10-V supply rail, the Q output will go high on the first positive-going edge of the clock signal. The high level of Q is used to drive T₂ into saturation, whereupon LED D₃ lights. That condition is maintained until the circuit is reset manually by pressing switch S₁. The LED so indicates that the circuit was actuated at least once, which is very useful if it is used as a sensor monitor which operates unattended for long periods. Note that such a memory function can not be obtained from the relay, because that is simply a 'slave' to the comparator output.

Inputs

The input of the sensor monitor consists of four electronic switches, IC_{3a}-IC_{3d}, and an oscillator built around IC_{1a} and IC_{1b}. The oscillator supplies a square wave signal with a frequency of

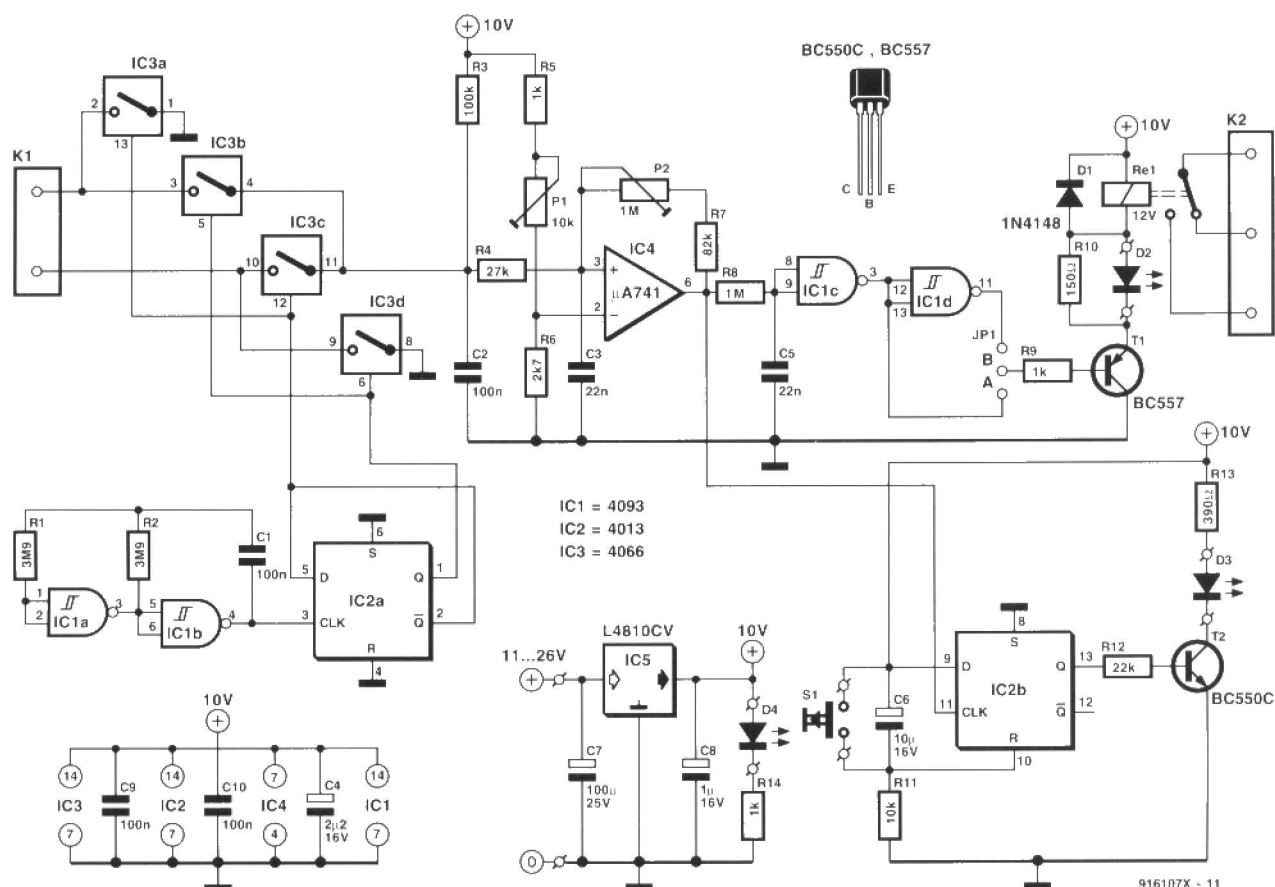


Fig. 1. The circuit consists of a comparator, a relay, and four electronic switches driven by an oscillator.

about 1 Hz. This signal is fed to bistable IC_{2a}, which divides it by two, and provides two complementary output signals with a frequency of 0.5 Hz, and a duty factor of 0.5. These signals are available on outputs Q (pin 1) and \bar{Q} (pin 2), and control the four electronic switches contained in IC₃.

Assuming that output Q is high, and \bar{Q} low, switches IC_{3b} and IC_{3d} are closed, and the other two, open. In other words, the 'left-hand' side of the sensor (which is wired to K₁), is connected to the +10 V line via IC_{3b} and resistor R₃, while the 'right-hand' side is taken to ground via IC_{3d}.

One second later, this situation is reversed: the \bar{Q} output of IC_{2a} is logic high, switches IC_{3a} and IC_{3c} are closed, and the other two, opened. The right-hand side of the sensor is then connected to the +10-V rail via IC_{3c} and R₃, while the other side is connected to ground via IC_{3a}. In other words, the sensor connections are 'reversed' at a rate of 0.5 Hz. The purpose of this arrangement will be discussed further on.

Low-pass filter R₄-C₃ prevents the comparator from noticing the opening and closing of the electronic switches

(unless the sensor is a polarized type, which will also be reverted to below).

Power supply

The circuit is powered by a ready-made mains adaptor, which is safer and (in many cases) less expensive than a separate transformer. The type of adaptor required is one with a direct output voltage between 11 V and 26 V. The adaptor output is stepped down to 10 V by a three-pin fixed voltage regulator Type L4810. The more common 7810 is not used here because it would require an input voltage of at least 13 V, which means that at least 3 V is 'wasted'. By contrast, the L4810 introduces a voltage drop of only 1 V, which means that less supply power is needed.

Applications

To start with, it is, of course, possible to use two electrodes to form a sensor. This could be used to monitor the conductivity or concentration of a certain solution. Alternatively, you may want to use an LDR (light-dependent resistor), which has a high resistance in the

dark, and a low resistance in the light. Consequently, the sensor voltage at the comparator input will be high in the dark, and low in the light.

A potentiometer may also be used as a positioning sensor to check the operation of a mechanical device. For temperature measurements, an NTC (negative temperature coefficient) or a PTC (positive temperature coefficient) resistor may be connected up.

The above sensors are all non-polarized. Consequently, they pass current in both directions, and may be connected both ways around. Polarized sensors may also be used. The simplest of these is created by connecting a diode in series with the previously mentioned LDR. Consequently, current can flow in one direction only. That has the following effect: as it grows dark, the sensor voltage rises to a level where the comparator toggles, and the relay is energized (or de-energized, depending on which jumper is fitted). However, as soon as the polarity of the sensor is reversed (by the oscillator and the electronic switches), the comparator will toggle again. This on/off change is repeated over and over again, so that the relay is switched on and off

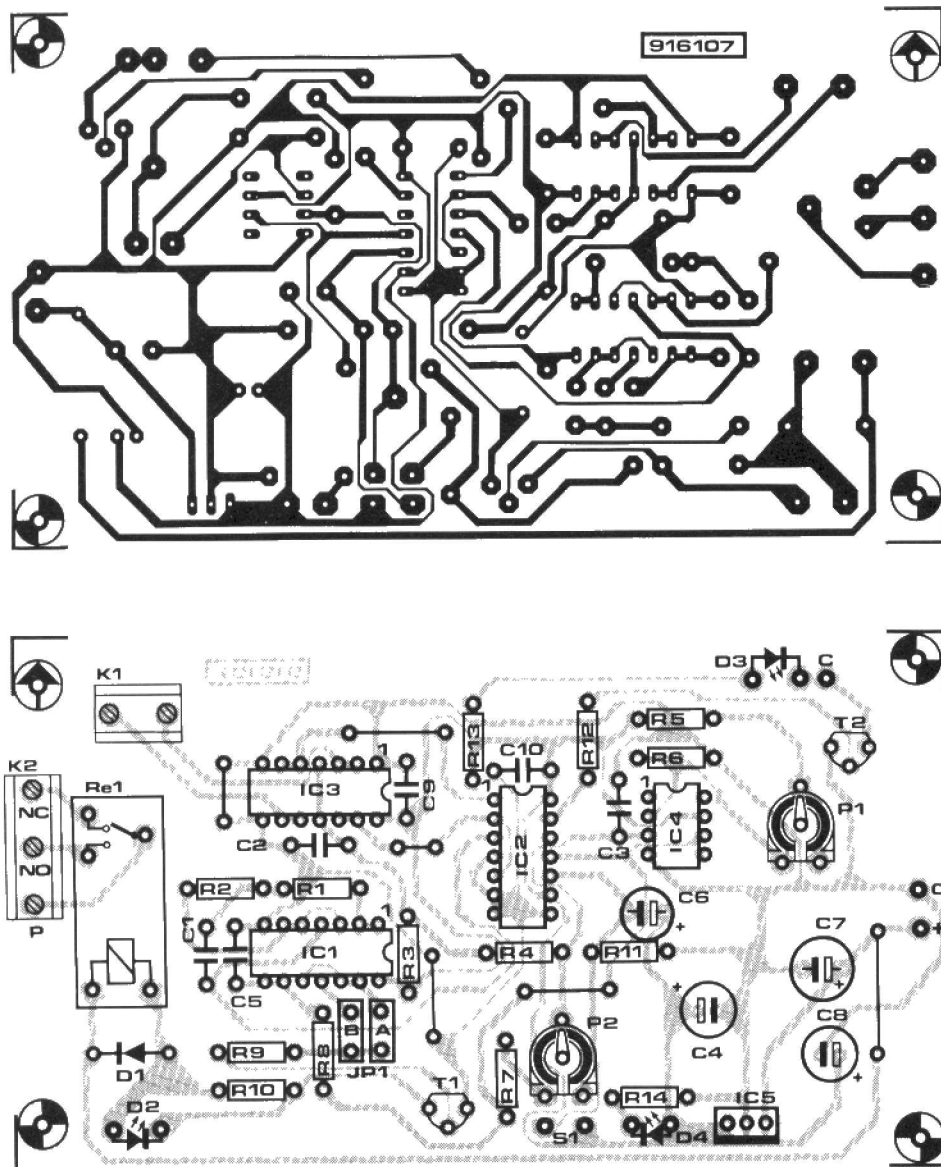


Fig. 2. Track layout (direct reading) and component mounting plan of the PCB designed for the sensor monitor (PCB not available ready-made).

at a rate of 0.5 Hz. In certain cases, this may boost the attention drawing effect of, for instance, an alarm siren connected to the relay contacts. The 'trick' may also be applied to the previously mentioned 'positioning' potentiometer.

A photodiode forms a polarized sensor without the help of an extra diode. Photodiodes may be connected either way around, taking into account that the operation of the relay changes 180 degrees. The same may, of course, be achieved by moving the jumper to the other position, or by swapping the NO and NC relay contacts.

Construction

The artwork of the printed circuit board designed for the sensor monitor is shown in **Fig. 2**. Unfortunately, this board is not available ready-made through the Readers Services, so that you have to produce it yourself from the drawings given, or build the circuit on prototyping board.

The board is populated in the usual way, that is, starting with the wire links and the low-profile parts, followed by the taller parts. The ICs are fitted last.

After a careful check on the solder work and the orientation of the polar-

COMPONENTS LIST

Resistors:

R1, R2 = 3M Ω
 R3 = 100k Ω
 R4 = 27k Ω
 R5, R9, R14 = 1k Ω
 R6 = 2k Ω
 R7 = 82k Ω
 R8 = 1M Ω
 R10 = 150 Ω
 R11 = 10k Ω
 R12 = 22k Ω
 R13 = 390 Ω
 P1 = preset 10k Ω
 P2 = preset 1M Ω

Capacitors:

C1, C2, C9, C10 = 100nF
 C3, C5 = 22nF
 C4 = 2 μ F 16V radial
 C6 = 10 μ F 16V radial
 C7 = 100 μ F 63V radial
 C8 = 1 μ F 16V radial

Semiconductors:

D1 = 1N4148
 D2, D4 = LED red 3mm
 D3 = LED green 3mm
 T1 = BC557
 T2 = BC550C
 IC1 = 4093
 IC2 = 4013
 IC3 = 4066
 IC4 = 741
 IC5 = L4810

Miscellaneous:

K1 = 2-way PCB terminal block, raster 7.5mm.
 K2 = 3-way PCB terminal block, raster 7.5mm.
 S1 = SPST push-button.
 Re1 = PCB mount relay, 12V, e.g. Siemens V23127-B0002-A101.
 Mains adaptor socket.
 Case: e.g., OKW A9030087 (150x80x50mm).

ized components, the board may be fitted into suitable enclosure. The photograph in **Fig. 3** shows our prototype, which may give you further ideas as regards construction. The circuit is then almost ready for use.

Adjustment

The reference voltage at the inverting input of the comparator may be varied between about 2 V and 7.3 V with preset P1. To enable the comparator to toggle, the sensor output voltage must lie in this range. Remember, the sensor forms a voltage divider together with R3 (100 k Ω). Consequently, to enable a

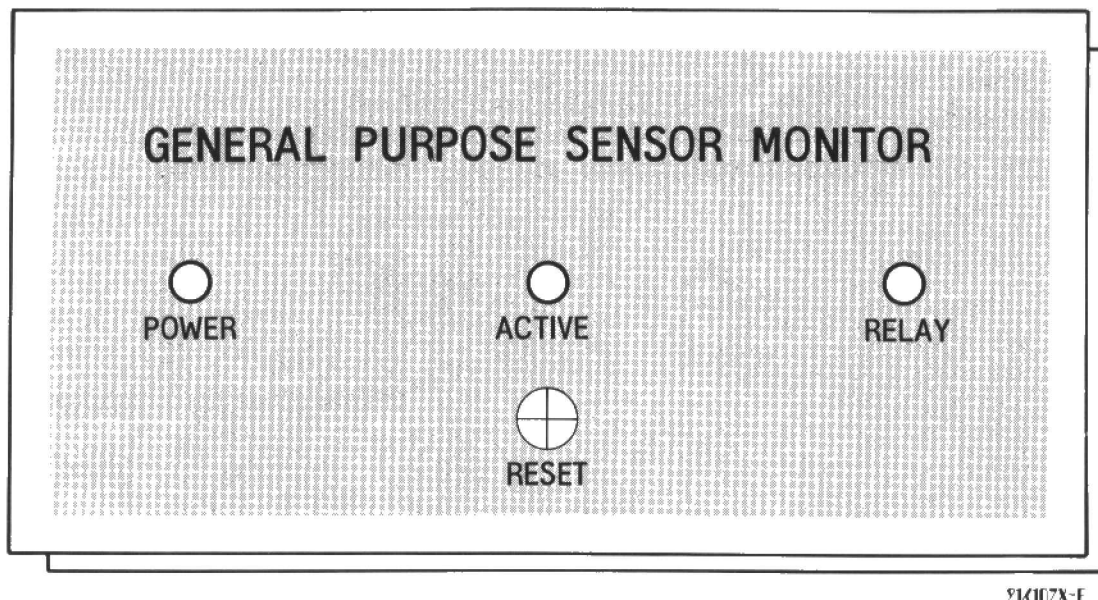


Fig. 3. Suggested front panel layout.

suitable switching threshold to be set, the sensor must have an impedance between about 32 k Ω and 270 k Ω . A sensor having an impedance of between 10 k Ω and 20 k Ω is, therefore, not suitable straight away, because then the voltage at the non-inverting input of the comparator can never become high enough for the comparator to toggle. If you still want to use such a sensor, you have to change the value of R_3 to satisfy the following two equations:

$$R_{\text{sens(min)}} / (R_{\text{sens(min)}} + R_3) \times 10 \text{ V} \approx 2 \text{ V};$$

and

$$R_{\text{sens(max)}} / (R_{\text{sens(max)}} + R_3) \times 10 \text{ V} \approx 7.3 \text{ V}.$$

Briefly, this means that the voltage divider formed by R_3 and the sensor has to be calculated again, whereupon the switching threshold and the amount of hysteresis can be adjusted with P_1 and P_2 respectively.

Correct adjustments of these two presets is awarded with good sensitive and an accurate switching point without relay 'chatter'.

Electrodes

Measuring the concentration of a saline solution is possible by measur-

ing its conductivity. Two electrodes (for instance, copper ones) are immersed in the solution, a current is sent through them, and the voltage drop is measured. Since pure water does not conduct, the resistance formed by the solution, and therefore the voltage across the electrodes, is a measure of the concentration of 'salt' ions in the solution. Ordinary tap water conducts only because it contains a fair concentration of dissolved salts, and, therefore, many (positive or negative) ions.

The sensor monitor could be used to keep a continuous check on a certain concentration level. Unfortunately, electrolysis occurs readily if a direct current is sent through the electrodes. Electrolysis causes a number of chemical reactions to occur at the electrodes. The result is usually gas, the gradual dissolving of one electrode, and deposits of metal ions on the other electrode. Obviously, these effects can easily distort the results of the conductivity measurement.

Fortunately, the above problems are easily avoided by using alternating current instead of direct current. In practice, this minimizes the effects of electrolysis at the electrodes, provided the frequency of the current is high enough. It seems that about 100 Hz is the absolute minimum for such measurements, which means that the 0.5-Hz signal produced in the switching circuit at the input of the present monitor is wide off the mark. To change the switching frequency to about 100 Hz, the values of the timing components in the oscillator are modified as follows: $R_1=R_2=39 \text{ k}\Omega$; $C_1=10 \text{ nF}$. Professional instruments of this type often use a much higher switching frequency: up to 10 kHz! ■

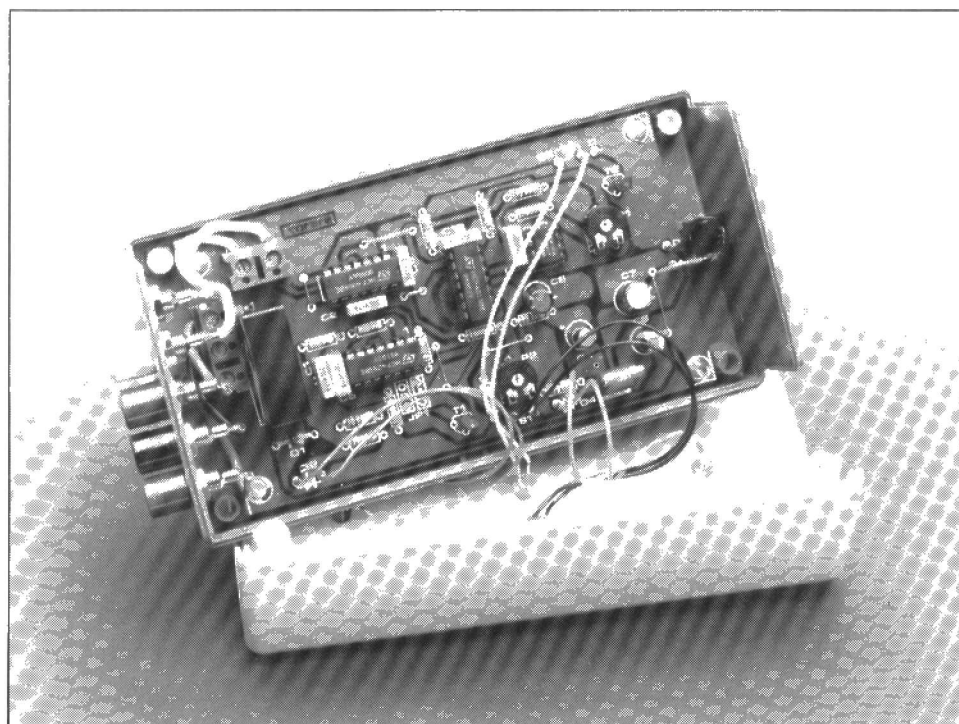


Fig. 4. Completed prototype.

80C535 HARDWARE/ASSEMBLER COURSE

PART 3: INTRODUCTION TO COMPARE/CAPTURE UNIT (CCU) AND INTERRUPTS

Software by Dr. M. Ohsmann

Since the CCU (compare/capture unit) of the 80C535 is functionally related to interrupts in general, these two subjects are discussed alongside each other in the present course instalment. When used in capture mode, the CCU enables, for instance, accurate time measurements to be performed by software. Similarly, the compare mode may be used to program a generator for variable pulsewidth signals. The timing of the CCU is arranged by Timer 2 in the 80C535. Some of the features of Timer 2 will be discussed here. Only a handful of components, and simple programs, are required to become familiar with the ins and outs of the CCU. As usual, the relevant programs may be found on your course disk.

The extended interrupt system

To some of you, some interrupts may already be familiar, for instance, those related to Timer 0 and Timer 1, and the external interrupts (P3.2=INT0 and P3.3=INT1). From the 8051/80C32 assembler course, you may also remember that individual interrupt events cause bits in the special function register TCON to be set. Provided the relevant interrupt has been enabled by setting the corresponding bits in the IEN register, an interrupt is then actually generated. In the 80C535, this system has been extended with a couple of interrupt sources. The extended architecture is shown in **Fig. 5**. Special attention should be drawn to the new external interrupts IEX2 to IEX6, which correspond to port bits P1.0 to P1.4 (although differently numbered). As illustrated in **Fig. 6**, the interrupt event then sets the corresponding bit in the IRCON register at address 0C0H. Bits IEX2 to IEX6 are automatically cleared when the interrupt routine is finished. Alternatively, they may be set and reset via software. To be able to enable these interrupts, the relevant bits in the IEN0 or IEN1 register (see **Fig. 7**) must be set. Remember, to be able to enable interrupts at all, the EAL bit (bit 7 in IEN0) must be set.

Some of you may already have noticed that the port bits of Port 1 have a number of additional functions in the 80C535. If one of these port lines is to be used as an input (which includes its use as an interrupt input), the output

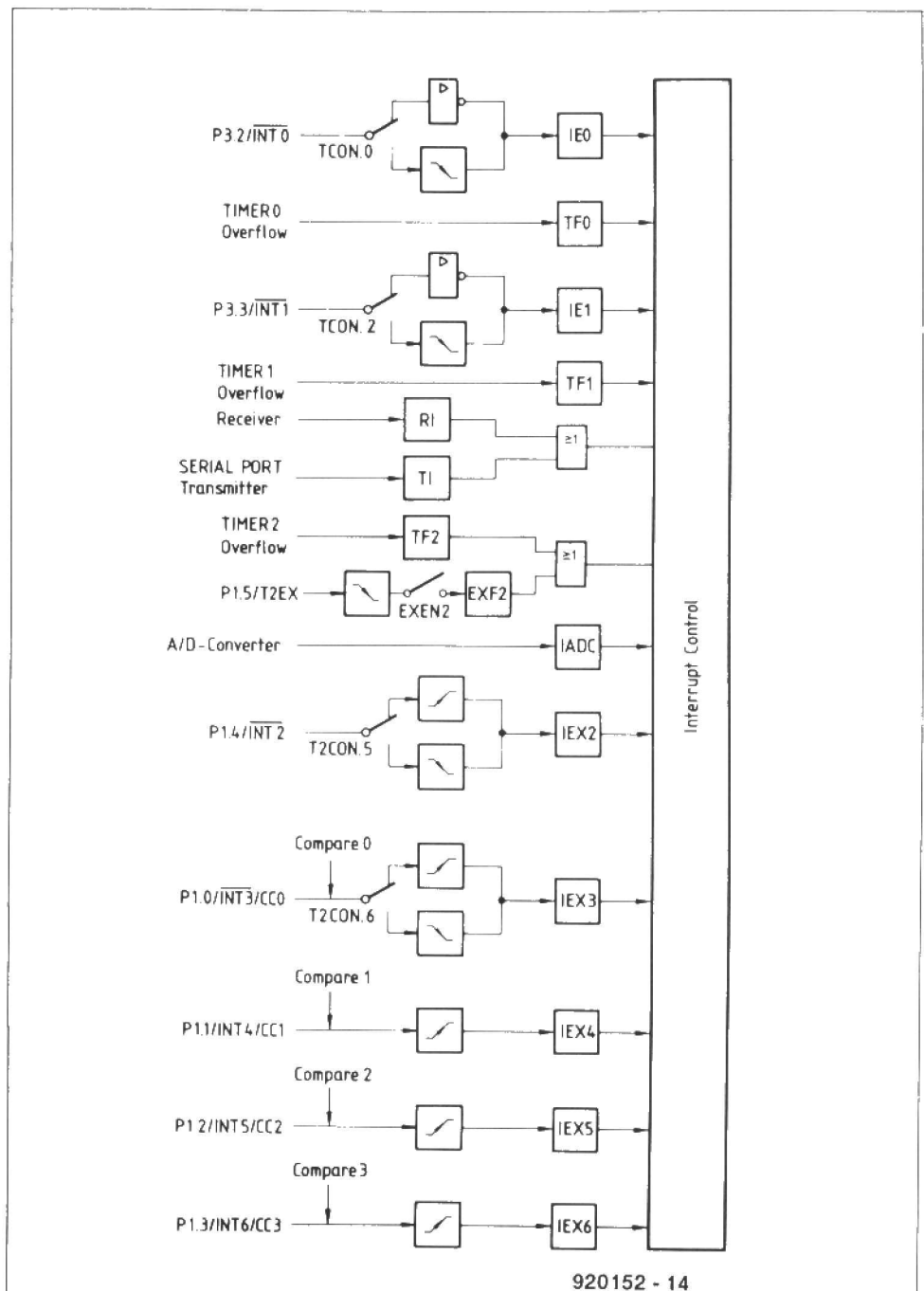


Fig. 5. Schematic showing the interrupt sources which can be used with the 80C535.

Special Function Register IRCON (Address 0C0H)

	0C7H	0C6H	0C5H	0C4H	0C3H	0C2H	0C1H	0C0H	
0C0H	EXF2	TF2	IEX6	IEX5	IEX4	IEX3	IEX2	IADC	IRCON

Bit	Function
IADC	A/D converter interrupt request flag. Set by hardware at the end of a conversion. Must be cleared by software.
IEX2	External interrupt 2 edge flag. Set by hardware when external interrupt edge was detected or when a compare event occurred at pin 1.4/INT2#/CC4. Cleared when interrupt processed.
IEX3	External interrupt 3 edge flag. Set by hardware when external interrupt edge was detected or when a compare event occurred at pin 1.0/INT3#/CC0. Cleared when interrupt processed.
IEX4	External interrupt 4 edge flag. Set by hardware when external interrupt edge was detected or when a compare event occurred at pin 1.1/INT4/CC1. Cleared when interrupt processed.
IEX5	External interrupt 5 edge flag. Set by hardware when external interrupt edge was detected or when a compare event occurred at pin 1.2/INT5/CC2. Cleared when interrupt processed.
IEX6	External interrupt 6 edge flag. Set by hardware when external interrupt edge was detected or when a compare event occurred at pin 1.3/INT6/CC3. Cleared when interrupt processed.
TF2	Timer 2 overflow flag. Set by a timer 2 overflow. Must be cleared by software. If the timer 2 interrupt is enabled, TF2 = 1 will cause an interrupt.
EXF2	Timer 2 external reload flag. Set when a reload is caused by a negative transition on pin T2EX while EXEN2 = 1. When the timer 2 interrupt is enabled, EXF2 = 1 will cause the CPU to vector the timer 2 interrupt routine. Can be used as an additional external interrupt when the reload function is not used. EXF2 must be cleared by software.

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Fig. 6. Interrupts cause certain bits in the IRCON register to be set.

state of the associated pin must be programmed as '1' (logic high). Fortunately, that is the default state after a reset, so no extra programming

is required. However, if the port was previously used as an output, it is recommended to return the relevant pins to 'input' (1) by explicit programming,

80C535 PROGRAMMING

You need the following to be able to follow the 80C535 hardware/assembly course:

Hardware:

- An 80C535 single-board computer as described in *Elektor Electronics* February 1994.
- An IBM PC or compatible with a serial port on COM1: or COM2:.

Software:

- Courseware disk (5.25 inch, 360K MSDOS format).
- EMON52 system EPROM, fitted on 80C535 SBC.

The courseware disk and EPROM are available as a set under order code **6221**. The disk is also available separately under order code 1811. For prices and ordering information, see page 70.

JOIN THE COURSE!

to make absolutely sure that they are inputs after a reset. That is also necessary if you want to use the alternative output functions of these pins, for instance, if pulsewidth modulated signals are generated (see example program 535XMP05.A51 on your disk).

The address vectors for different types of interrupt routine are shown in **Fig. 8**. As with the 80C32, we are faced with a problem: since the monitor EPROM will normally reside at the ad-

Special Function Register IEN0 (Address 0A8H)

	0AFH	0AEH	0ADH	0ACH	0ABH	0AAH	0A9H	0A8H	
0A8H	EAL	WDI	ET2	ES0	ET1	EX1	ET0	EX0	IEN0

 This bit is not used for interrupt control.

Bit	Function
EX0	Enables or disables external interrupt 0. If EX0 = 0, external interrupt 0 is disabled.
ET0	Enables or disables the timer 0 overflow interrupt. If ET0 = 0, the timer 0 interrupt is disabled.
EX1	Enables or disables external interrupt 1. If EX1 = 0, external interrupt 1 is disabled.
ET1	Enables or disables the timer 1 overflow interrupt. If ET1 = 0, the timer 1 interrupt is disabled.
ES0	Enables or disables the serial channel 0 interrupt. If ES0 = 0, the serial channel 0 interrupt is disabled.
ET2	Enables or disables the timer 2 overflow or external reload interrupt. If ET2 = 0, the timer 2 interrupt is disabled.
EAL	Enables or disables all interrupts. If EAL = 0, no interrupt will be acknowledged. If EAL = 1, each interrupt source is individually enabled or disabled by setting or clearing its enable bit.

Special Function Register IEN1 (Address 0B8H)

	0BFH	0BEH	0BDH	0BCH	0BBH	0BAH	0B9H	0B8H	
0B8H	EXEN2	SWD1	EX6	EX5	EX4	EX3	EX2	EADC	IEN1

 This bit is not used for interrupt control.

Bit	Function
EADC	Enables or disables the A/D converter interrupt. If EADC = 0, the A/D converter interrupt is disabled.
EX2	Enables or disables external interrupt 2/capture/compare interrupt 4. If EX2 = 0, external interrupt 2 is disabled.
EX3	Enables or disables external interrupt 3/capture/compare interrupt 0. If EX3 = 0, external interrupt 3 is disabled.
EX4	Enables or disables external interrupt 4/capture/compare interrupt 0. If EX4 = 0, external interrupt 4 is disabled.
EX5	Enables or disables external interrupt 5/capture/compare interrupt 0. If EX5 = 0, external interrupt 5 is disabled.
EX6	Enables or disables external interrupt 6/capture/compare interrupt 0. If EX6 = 0, external interrupt 6 is disabled.
EXEN2	Enables or disables the timer 2 external reload interrupt. EXEN2 = 0 disables the timer 2 external reload interrupt. The external reload function is not affected by EXF2.

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Fig. 7. Registers IEN0 and IEN1 are used to enable interrupts.

Interrupt request flags	Interrupt vector address	Interrupt source
IE0	0003H	External interrupt 0
TF0	000BH	Timer overflow
IE1	0013H	External interrupt 1
TF1	001BH	Timer 1 overflow
RI0:TI0	0023H	Serial channel 0
TF2:EXF2	002BH	Timer 2 overflow ext. reload
IADC	0043H	A/D converter
IEX2	004BH	External interrupt 2
IEX3	0053H	External interrupt 3
IEX4	005BH	External interrupt 4
IEX5	0063H	External interrupt 5
IEX6	006BH	External interrupt 6
RI1:TI1	0083H	Serial channel 1
CTF	009BH	Compare timer overflow

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Fig. 8. Overview of fixed interrupt vector addresses.

the 'old' monitor EPROM to follow the present course without problems, there are no example programs on the course disk that make use of the extended interrupts offered by the 80C535. Nonetheless, some know-how on interrupts will be required to fully understand the operation of Timer 2 (fortunately, a corresponding interrupt was already foreseen in the 'old' monitor, EMON51).

Owing to lack of space, the interrupt priority assignment used in the 80C535 is not discussed in this course. Details on this subject may be found in the Siemens/Intel datasheets.

Timer 2: the CCU core

Before we run into a lot of confusion, it should be made clear that the 8052 and 8032 microcontrollers also sport a 'Timer 2'. Timer 2 in the 80C535, however, works in a totally different way, because it is controlled by other bits in other SFRs. The 80C535 is, therefore, not compatible with the 8052 in this respect. It is, however, compatible with the 8051, simply because the latter does not have a Timer 2.

For now, let us concentrate on Timer 2 in the 80C535. This is a 16-bit timer consisting of SFRs TL2 (address 0CCH, LS counter byte) and TH2 (address 0CDH, MS counter byte). The clock signal for Timer 2 can be derived from different signals. The input circuit is shown in Fig. 9. Figure 10 shows the configuration of the timer in 'reload' mode, while Fig. 11 lists the function of the bits in the T2CON special function register (at address 0C8H), which serves to control Timer 2. As can be deduced from Fig. 9, the timer clock signal can be generated in four ways. The selection is made by programming bits 1 (T2I1) and 0 (T2I0) in register T2CON.

1. If both bits are at 0, the counter (timer) stops, since it is no longer supplied with a clock signal.

2 The bit combination '01' selects the so-called timer function, when the internal clock is used to clock the counter. The internal clock is the quartz crystal frequency divided by 12. Since a 12-MHz quartz crystal is used, the internal clock is a 1-MHz signal, but only if the available divide-by-two prescaler is switched off (bit 7=T2PS=0 in T2CON). If the prescaler is switched on (by setting the T2PS bit), the internal clock frequency is lowered to 500 kHz.

3. If bits T2I1 and T2I0 are given the value '10', the so-called counter function is selected, when the signal applied to the P1.7/T2 pin is used as a clock. That allows Timer 2 to be used to count external events. The counter

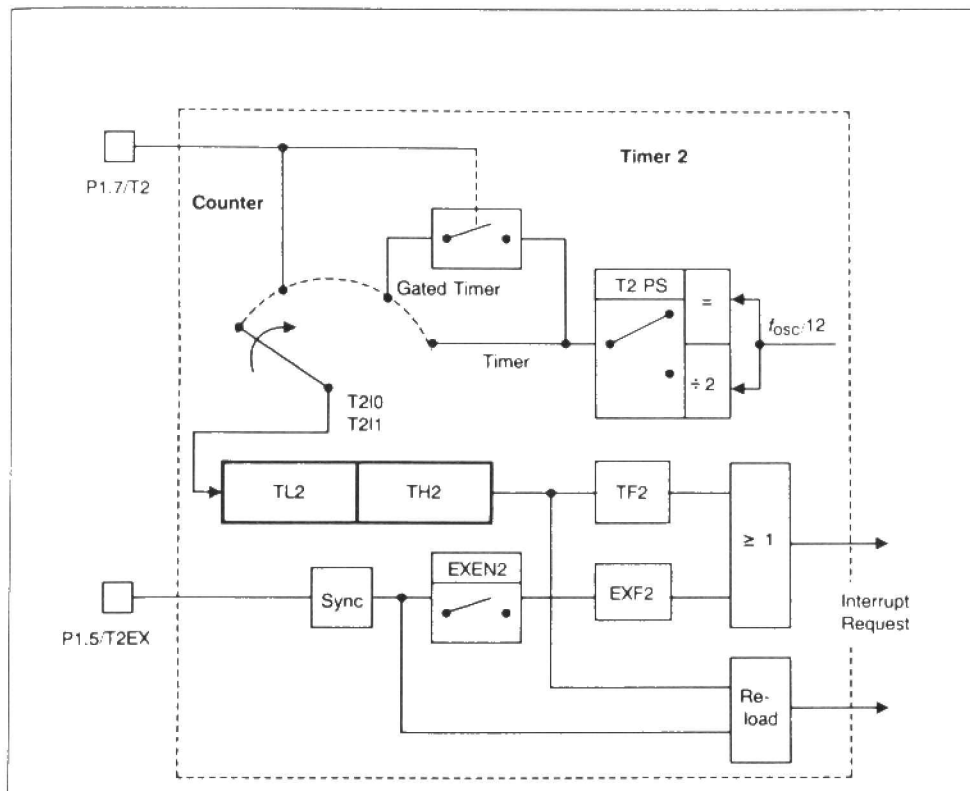


Fig. 9. Input circuit of counter/timer 2.

addresses shown in Fig. 8, the interrupt routines seem out of your control. This problem is solved by the LINK mechanism provided by the EMON51 monitor EPROM, which allows the interrupt routines to be 'chained'.

EMON51 is capable of setting up links for 8031/8051 and 80C32 inter-

rupts only. By contrast, the new monitor, EMON52, handles all 80C535 interrupts also. Consequently, you must use EMON52 instead of EMON51 if you want to use the monitor to assist with programming interrupts which are specific to the 80C535. Since it was desired to enable readers in possession of

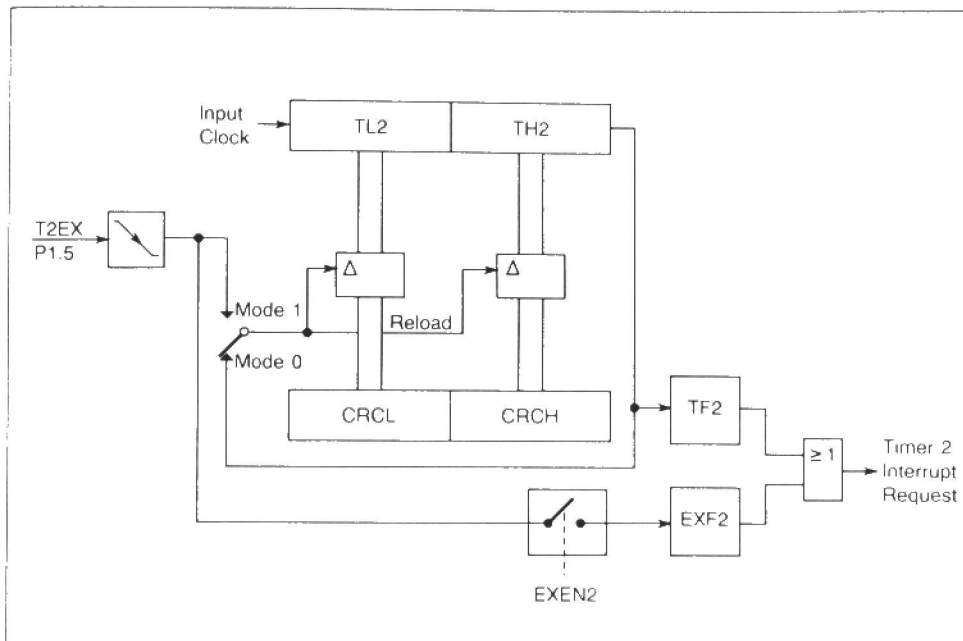


Fig. 10. Timer 2 in reload mode.

Special Function Register T2CON

	0CFH	0CEH	0CDH	0CCH	0CBH	0CAH	0C9H	0C8H	
0C8H	T2PS	0FFH	0FFH	T2R1	T2R0	T2CM	T2I1	T2I0	T2CON

These bits are not used in controlling the CCU.

Timer 2 control register. Bit-addressable register which controls timer 2 function and compare mode of registers CRC, CC1 to CC3.

Bit	Function
T2I1	T2I0
0	0
0	1
1	0
1	1
T2R1	T2R0
0	X
1	0
1	1
T2CM	
T2PS	

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Fig. 11. The functions of Timer 2 are controlled via bits in the T2CON register.

is clocked on the negative-going (falling) edge of the external signal. It should be noted, however, that the logic state of pin P1.7 is detected only once during every machine cycle. Consequently, the maximum count rate equals 500 kHz. Also, the 'low' and 'high' times of the input signal must have a minimum length of one machine cycle, to enable a signal edge to

be detected. Remember, a machine cycle equals 12 times the quartz cycle time, i.e., one microsecond at the quartz frequency used on the 80C535 SBC.

4. If T2I1 and T2I0 are both at '1', Timer 2 is programmed to function as a 'gated timer'. In this mode, too, the internal clock (with or without the T2PS prescaler) is used to clock the timer.

However, the clock signal only reaches the counter if P1.7 is at '1'. This mode may be used, for instance, to determine the pulse/pause ratio of signals. That also concludes the discussion of the different types of signal that may be used to clock Timer 2. The T2CM bit (bit 2 in T2CON) is skipped for the moment, and we turn our attention to bits 3 and 4 in T2CON.

Timer 2 reload

A number of programming options are available to determine the program flow when Timer 2 overflows at its maximum counter state, 0FFFFH, or 65535. In any case, this event causes the TF2 bit (bit 6 in the ICON, see Fig. 6) to be set. What happens next is determined by the state of bit 4 (T2R1) and bit 3 (T2R0), which are both in the T2CON SFR. If T2R1 is at '0', the so-called reload mode is disabled, and the counter simply starts at 0 again. If T2R1 is at '1', Timer 2 is operated in reload mode, in which bit T2R0 determines when the counter is reloaded with the value contained in the reload register pair CRCL-CRCH (compare Fig. 10). In mode 0 (T2R0 = 0), the counter is loaded after the overflow. The reload value is then contained in the CRCL (LS byte; 0CAH) and CRCH (MS byte; 0CBH) register pair. If the pair contains, for example, the value 0FFFCH (-4), the counter counts 0FFFFH, 0FFFCH, 0FFFDH, 0FFFEH, 0FFFFH, 0FFFCH, and so on. If the T2R1 bit is at '1', the counter is reloaded any time a negative pulse edge is detected at pin P1.5. This option is particularly useful if you want to synchronize the counter with an external signal. For instance, a phase control circuit may be realized by driving pin P1.5 with a 50-Hz signal derived from the mains. This effectively synchronizes Timer 2 with the mains frequency. At a count rate of 1 MHz (internal clock used without the prescaler), that enables a phase control circuit with a resolution of one microsecond to be realized.

If bit EXEN2 (bit 7 in the IEN1 register, see Fig. 7) is set, each reload signal edge at P1.5 also causes bit EXF2 (bit 7 in ICON, see Fig. 6) to be set. This can be interrogated by software, while an interrupt may also be generated by enabling the relevant interrupt.

Next time: in next month's final instalment of the course we will conclude the discussion of the CCU and the Timer 2 operation using a couple of programming examples.

'STAMP' BASIC COMPUTER

It's small, easy to program, flown in from the States, affordable, based on a RISC processor, and a real block buster when it comes to developing turnkey software in less time than you ever dreamed possible. It's the wonderful stamp-sized computer that runs BASIC. Real cute!

At first glance, the Stamp may seem fairly minimal — and in fact, it is, hence its name. But, with software that fully utilizes all available hardware, the Stamp gives you useful and powerful features — without the cost of hardware.

The Stamp has a size of about 5x2.5 cm (2x1 in.), and consists of two main components. The brain of the Stamp is a PIC16C56 microcontroller¹ running the PBASIC interpreter developed by Parallax Inc. A 256-byte EEPROM holds a tokenized version of your BASIC program, which is read and executed by the interpreter contained in the PIC. The remainder of the Stamp is taken up by a 4-MHz resonator, a 5-V regulator, and a 9-V PP3 battery clip. Also included is a small prototyping area, which provides connection points



Sources: Parallax Inc. and K.H. Eichler (Wilke Technology).

for the Stamp's eight I/O lines, 5-V supply, unregulated supply, and ground.

The BASIC Stamp is programmed in the simple BASIC language. The language includes familiar instructions such as FOR...NEXT, IF...THEN, and GOTO, as well as SBC-specific instructions such as SERIN (serial input) and BUTTON (button input). Each instruction takes two or three bytes of EEPROM space, resulting in a maximum program size of 80 to 100 instructions. As for execution speed, programs run at the rate of about 2,000 instructions per second.

To write programs for the Stamp, you will need a Development Kit. The kit includes editor software for a PC, a cable to connect the Stamp to the PC, one BASIC Stamp, and a manual. By connecting the Stamp to your PC's parallel port and then running the editor, you can write BASIC programs and then download them to the Stamp. If you are familiar with the BASIC language, it is a matter of minutes before you have your first program running. Furthermore, a number of application notes are available free of charge from Parallax Inc. to help you become acquainted with programming the computer.

It is possible to use the BASIC interpreter developed by Parallax Inc. in your own designs. This can be achieved by purchasing 'bare' interpreter chips from Parallax Inc. at prices ranging from \$5 (1,000 off) to \$18 (one off). Add to that a 256-EEPROM, a 4-MHz resonator and a power supply, and you can start using your own miniature BASIC computer. Applications? What about an LCD user-interface terminal, interfacing an A-D converter, a matrix keypad in/LCD screen out circuit, a servo motor driver, a pulse meter, a morse code generator, an intelligent battery charger, or a serial stepper motor controller? The list can be extended to any length, depending only on your creativity.

Circuit description

Figure 1 shows the circuit diagram of the Stamp board supplied by Parallax Inc. as part of their Development Kit. The component count is, well, low! The component locations on the board are shown in **Fig. 2**.

The microcontroller used is a PIC16C56XT preloaded with Parallax's PBASIC interpreter. The PIC device also contains an I/O port, a serial interface and a clock oscillator. The program memory is formed by a 93LC56

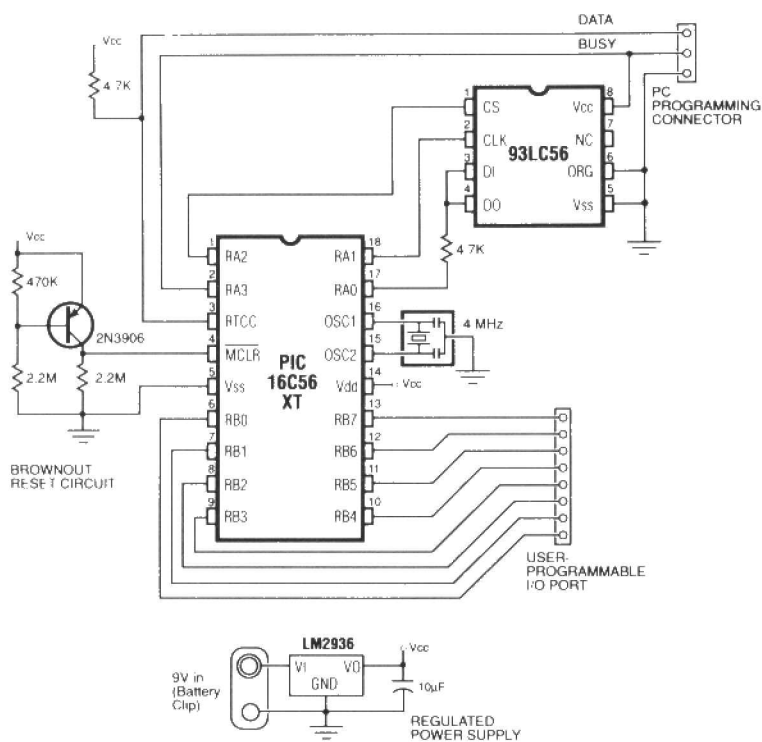
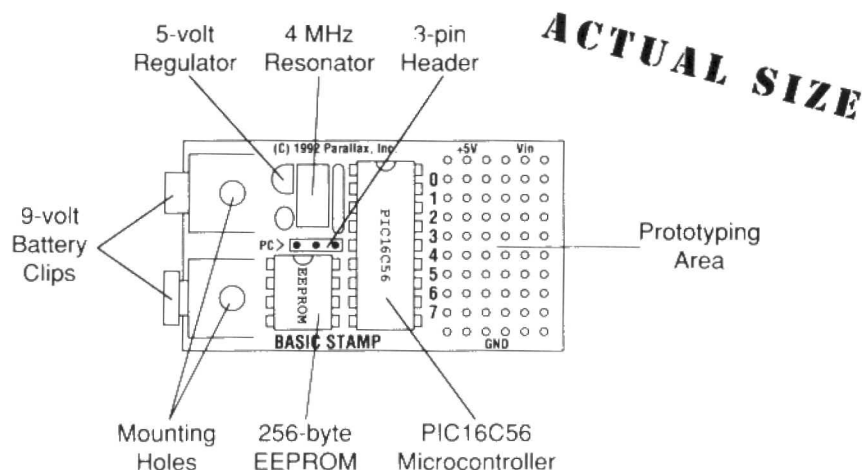


Fig. 1. Schematic of the Stamp single-board BASIC computer.



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Fig. 2. Locations of the main components on the BASIC Stamp.

EEPROM which retains the BASIC program even in the absence of the supply voltage. The EEPROM has a storage capacity of 256 bytes, allowing a program of between 80 and 100 lines of BASIC to be stored.

An on-board low-drop 5-V voltage regulator allows the Stamp to be powered from any d.c source with an output voltage between 6 V and about 15 V. In most cases, a 9-V PP3 size battery will be used to power the Stamp.

The schematic shows a power-down circuit based on one transistor and three resistors. Apart from ensuring a good reset no matter how long the Stamp has been off, the reset circuit also clears the PIC microcontroller after a 'brown-out'. A brown-out occurs when the supply voltage drops below 5 V, but not low enough to allow the chip's reset function to operate.

The Stamp offers a clever energy-saving power-down scheme which is controlled by three BASIC instructions: NAP, SLEEP and END. These allow the Stamp to 'sleep' at a current consumption of about 20 μ A, while all outputs retain their logic level.

The eight I/O lines may be used for many purposes, even for resistance measurement using the BASIC 'pot' command. Each I/O line is capable of supplying up to about 20 mA. However, the total load on all lines may not exceed 40 mA.

Using the Stamp editor

The diskette in the Stamp Development Kit contains a simple editor which runs on a DOS PC. The editor offers the following functions: Run, Load, Save and Quit. Once you have the editor running, the screen is available to write your BASIC program. If you are ready to test it, download the program to the Stamp using the ALT-R (Run) com-

mand. The BASIC program is compiled by the PC, and copied to the Stamp in tokenized form via the PC's parallel printer (Centronics) port. The progress of the download operation can be viewed as a horizontal bar, which also indicates the amount of EEPROM memory space left in the Stamp.

If the program does not function as expected, return to the editor, and change the BASIC commands as required. Simple word processing commands like cursor movement, copy, cut, paste and search/replace are available for that purpose. The syntax and program formatting rules are explained in detail in the manual that comes with the Stamp Development Kit. To save you a lot of typing, the program disk in the kit also contains 14 programs which belong with application notes published for the Stamp.

PBASIC command set

The PBASIC command set can be subdivided into eleven groups:

1. Branching
2. Looping
3. Numerics
4. Digital in/out
5. Serial in/out
6. Analogue in/out
7. Sound
8. EEPROM access
9. Time
10. Power control
11. Program debugging

In addition to the commands available most BASIC dialects, there are a number of Stamp-specific commands which allow, for instance, an external circuit to generate analogue voltages, or measure resistance values. Additionally, there are commands to generate tones, and to set up serial communication be-

tween a chain of Stamps or other ancillary circuits, in other words, a kind of network 'on a shoestring'.

As regards variables used in the BASIC programs, the following should be observed:

- » the variables area is limited to 16 bytes;
- » of these, two bytes are required for the I/O lines;
- » the remaining 14 bytes may be used as word variables (W0-W6) and byte variables (B0-B13). Of these, B0 and B1 (W0) may be used as bit variables 0-15. Of the two bytes used for the I/O lines, the first indicates the state of the relevant line (high or low), and the second, the direction (input or output). There are several ways of addressing individual lines, for instance, by programming Port.0, Pins.0 or Pin0, Port.8, Dirs.0 or Dir0. With the rest of the variables, it should be noted that W6 is used as a software stack whenever GOSUB commands are executed.

The SYMBOL command enables you to assign names different from B0-B13 and W0-W6 to the variables. For instance:

```
symbol switch = pin0
```

Comments can be added to make the program more readable. They begin with an apostrophe (') and continue to the end of the line. The well-known REM command may be used as an alternative.

Very conveniently, labels may be used instead of line numbers to branch within the program. For instance:

```
loop: toggle pin0
      goto loop
```

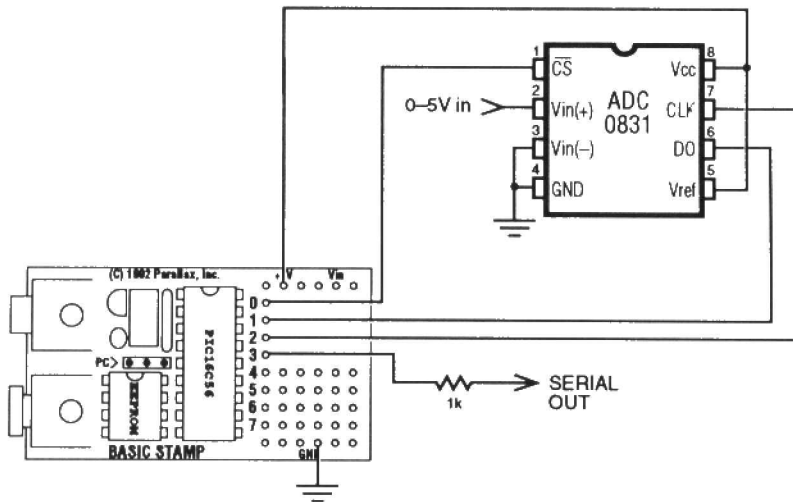
Finally, as regards general formats, the editor is case sensitive, except when processing strings (such as "stamp"). Multiple instructions and labels can be combined on the same line by separating them with colons (:). For instance,

```
dirs = 255 : for b2 = 0 to 100 : pins = b2 : next
```

An example application

The following application note, originally published by Parallax, Inc. as no. 2, presents the hardware and software required to interface an 8-bit serial analogue-to-digital converter to the Parallax BASIC Stamp. The application schematic is shown in Fig. 3.

The BASIC Stamp's instruction 'pot' performs a limited sort of analogue-to-digital conversion. It lets you interface nearly any kind of resistive sensor to the Stamp with a minimum of difficulty. However, many applications call for a true voltage-mode analogue-to-



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Fig. 3. Circuit to accompany AD_CONV.BAS.

```

' PROGRAM: ad_conv.bas
' BASIC Stamp program that uses the National ADC0831 to acquire analog data and output
' it via RS-232.

Symbol CS      =      0
Symbol AD      =      pin1
Symbol CLK     =      2
Symbol S_out   =      3
Symbol data    =      b0
Symbol i       =      b2

setup:  let pins = 255                ' Pins high (deselect ADC).
        let dirs = %11111101        ' S_out, CLK, CS outputs; AD input.

loop:   gosub conv                  ' Get the data.
        serout S_out,N2400,{#b0,13,10} ' Send data followed by a return and linefeed.
        pause 2000                  ' Wait 2 seconds.
        goto loop                  ' Do it forever.

conv:   low CLK                     ' Put clock line in starting state.
        low CS                      ' Select ADC.
        pulsout CLK, 1              ' 10 us clock pulse.
        let data = 0                ' Clear data.
        for i = 1 to 8              ' Eight data bits.
        let data = data * 2          ' Perform shift left.
        pulsout CLK, 1              ' 10 us clock pulse.
        let data = data + AD         ' Put bit in LSB of data.
        next i                      ' Do it again.
        high CS                     ' Deselect ADC when done.
        return

```

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Fig. 4. Listing of AD_CONV.BAS.

digital converter (ADC). One that is particularly suited to interfacing with the Stamp is National Semiconductor's ADC0831.

Interfacing the ADC0831 requires only three input/output lines, and of these, two can be multiplexed with other functions (or additional ADC0831s). Only the chip-select (CS) pin requires a dedicated line. The ADC's range of input voltages is controlled by the V_{REF} and $V_{IN(-)}$ pins. V_{REF} sets the voltage at which the ADC will return a full-scale output of 255, while $V_{IN(-)}$ sets the voltage that will return 0.

In the example application, $V_{IN(-)}$ is

at ground, and V_{REF} is at +5 V; however, these values can be as close together as 1 V without harming the device's accuracy or linearity. You may use diode voltage references or trim pots to set these values.

The sample program is listed in Fig. 4. It reads the voltage at the ADC's input pin every two seconds, and reports it to the PC via a 2400-baud serial connection. The subroutine 'conv' handles the details of getting data out of the ADC. It enables the ADC by pulling the CS line low, then pulses the clock (CLK) line to signal the beginning of a conversion. The program then en-

ters a loop in which it pulses CLK, gets the bit on pin AD, adds it to the received byte, and shifts the bits of the received byte to the left. Since BASIC traditionally does not include bit shift operations, the program multiplies the byte by two to perform the shift.

When all bits have been shifted into the byte, the program turns off the ADC by returning CS high. The subroutine returns with the conversion result in the variable 'data'. The whole process takes about 20 milliseconds.

You can add more ADC0831s to the circuit as follows: connect each additional ADC to the same clock and data lines, but assign it a separate CS pin. Modify the 'conv' subroutine to take the appropriate CS pin low when it needs to acquire data from a particular ADC. That's it!

The program may be downloaded from the Parallax Bulletin Board system in the USA under the file name AD_CONV.BAS. You can reach the BBS at (+1) 916 624-7101.

Who, what, where?

In addition to the BASIC Stamp Development Kit sold by Parallax Inc., Wilke Technology of Germany supply a range of products, including a compiler, an extensive hardware development system, and different types of Stamp SBC. It should be noted that these products are aimed mainly at advanced users, which is reflected by the cost. The hardware development system marketed by Wilke Technology is much more elaborate than the Development Kit supplied by Parallax.

To request information, prices, or order Stamp-related products, contact

Parallax Inc., 3805 Atherton Road, #102, Rocklin, CA 95765, U.S.A. Tel. (+1) 916 624-8333. Fax: (+1) 624-8003. BBS: (+1) 916 624-7107 (300-14,400 bps; no parity; 8 data bits; 1 stop bit).

Wilke Technology products are available from

Wilke Technology, Postfach 1727, Krefelder Str. 147, D-5100 Aachen, Germany. Tel. (+49) 241 154071. Fax: (+49) 241 158475.

In Hungary, contact

Humansoft, Ltd., H-1149 Budapest, Angol u. 24/b, Hungary. Tel. (+36) 1163 2879, fax: (+36) 1251 3673.

Further distributor information may be obtained from Parallax Inc.

Note:

1. See also 'PIC programmer' in the March 1994 issue of *Elektor Electronics*.

FIGURING IT OUT

PART 16 – MORE ABOUT FOURIER

By Owen Bishop

This series is intended to help you with the quantitative aspects of electronic design: predicting currents, voltage, waveforms, and other aspects of the behaviour of circuits.

Our aim is to provide more than just a collection of rule-of-thumb formulas.

We will explain the underlying electronic theory and, whenever appropriate, render some insights into the mathematics involved.

Last month we described how the Fourier series is used to represent any periodic waveform. To recapitulate, the series consists of:

- constant (d.c.) term
- +
- cosine terms
- +
- sine terms.

The constant term and the coefficients of the cosine and sine terms are found by integration:

$$A_0 = \frac{1}{2\pi} \int_0^{2\pi} y dt \quad [\text{Eq. 123}]$$

$$a_n = \frac{1}{\pi} \int_0^{2\pi} y \cos nt dt \quad [\text{Eq. 124}]$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} y \sin nt dt \quad [\text{Eq. 125}]$$

The constant term, which equals the average value of the variable (for example, voltage) during one cycle, can sometimes be found by geometrical means. We are often able to simplify the integrations by using the standard integrals given in Box 2 of Part 15. A frequent result of simplification is that the series for a given waveform has no cosine terms or no sine terms. Now we will look at some further ways of simplifying the calculations.

Even functions

An even function is one which is symmetrical about the y-axis. It is as if the y-axis acts as a mirror, reflecting the curve of the waveform for positive values of x on to the negative side of the axis. **Figure 131** shows some examples of even functions.

Mathematically, we can express this by:

$$f(x) = f(-x).$$

If a waveform is an even function, we can say, without any need for integrations, that:

- it may or may not have a con-

stant term;

- it has cosine terms;
- it has no sine terms.

An obvious example of an even function is the cosine waveform of **Fig. 131a**, which has a cosine term and no sine terms. Whether or not it has a constant term depends on whether it is superim-

posed on a constant d.c. level (as, for example, is the waveform of **Fig. 131b**). If you find that a waveform is symmetrical about the y-axis, you need not waste time by trying to evaluate the integral of Eq. 125.

Odd functions

These are symmetrical about the origin. If we imagine the curve spun round through 180° around a centre located at the origin, it comes to lie on itself. **Figure 132** shows some odd functions. The characteristic features of an odd function are:

- it has no constant term;
- it has no cosine terms;
- it has sine terms.

In short, an odd function has only sine terms. Since it is symmetrical about the origin, it can never have a constant term. Between them, even and odd functions cover most of the waveforms we are likely to meet in electronics, but there are a few other recognizable types of waveform that yield series with distinctive features. The next two headings deal with these.

Half-wave inversion

In **Fig. 133**, the waveform between $t = 0$ and $t = \pi$ is repeated, but inverted, between $t = \pi$ and $t = 2\pi$. This is known as **half-wave inversion**. The Fourier series for such a waveform has

- no constant term;
- no even cosine terms;
- no even sine terms.

The effects of half-wave inversion and the kinds of symmetry are cumulative. The waveform of **Fig. 133a** has odd symmetry and half-wave inversion. Because it has odd symmetry (and also because it has half-

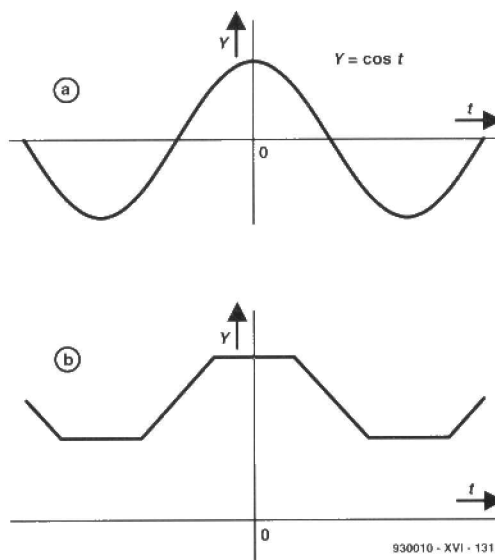


Fig. 131

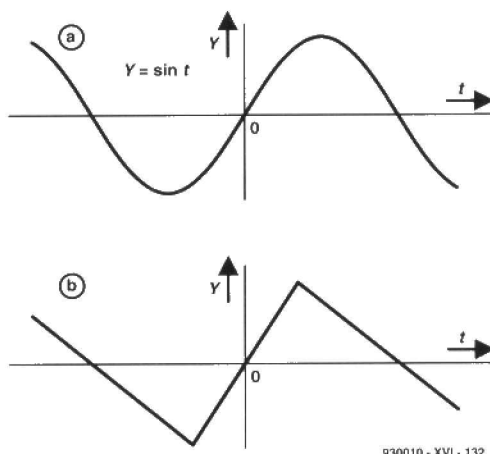


Fig. 132

wave inversion), it has no constant term. Because it has odd symmetry, it has no cosine terms. Because it has half-wave symmetry, it has no even sine terms. We are left with a series that has only odd sine terms. By contrast, the waveform of **Fig. 133b** has even symmetry and half-wave inversion. It therefore has no constant term and no sine terms. It has only odd cosine terms.

Half-wave repetition

The waveform of **Fig. 134** is repeated in the second half of the cycle. For such a waveform, the series has:

- possibly a constant term;
- no odd cosine terms;
- no odd sine terms.

The example here has a constant term. Removing the constant term of this example would shift the curve down, giving it odd symmetry. It therefore has only even sine terms. This rule does not necessarily eliminate the need to calculate all three of A_0 , a_n , and b_n , but does at least provide a check that your calculations are correct.

Square waves

The waveforms we have analysed so far have all been continuous within the period 0 to 2π . Now we will tackle a waveform that has an abrupt change of level during the cycle. **Figure 135** is a square wave with a mark:space ratio of 1. We have arbitrarily taken the 'high' level to be 3. This is a piecewise function and, to find the series, we have to deal with each part of the function separately. First of all, the constant term is the sum of two integrals:

$$A_0 = \frac{1}{2\pi} \int_0^\pi 3 dt + \frac{1}{2\pi} \int_\pi^{2\pi} dt$$

In this example, the second integral has zero value:

$$\begin{aligned} A_0 &= \frac{1}{2\pi} [3t]_0^\pi + 0 \\ &= \frac{3}{2\pi} [\pi - 0] = 1.5 \end{aligned}$$

This result could have more readily been obtained by inspecting the graph and noting that the average value of y is 1.5.

For the value of a_n we again integrate for both parts of the waveform:

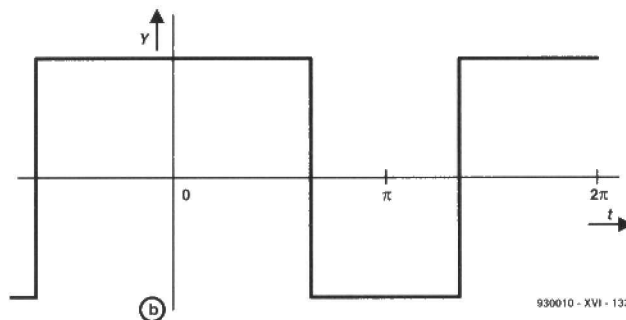
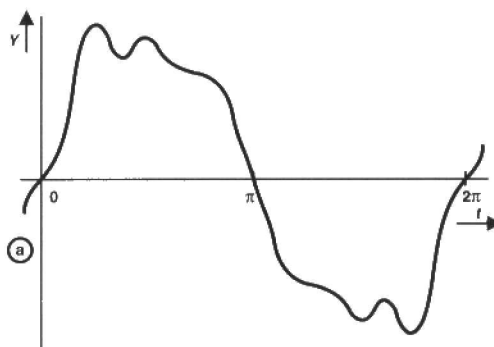


Fig. 133

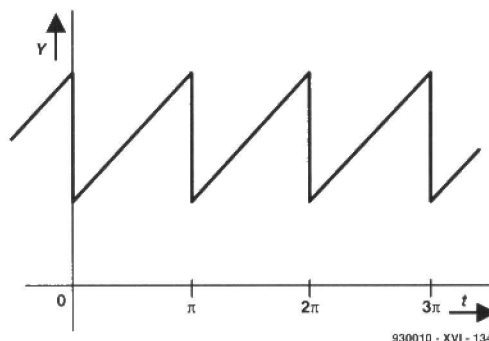


Fig. 134

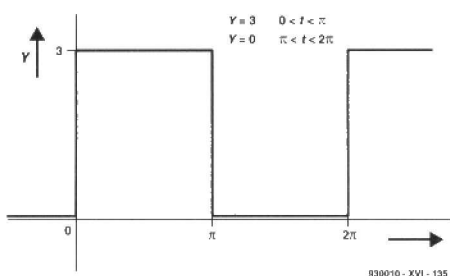


Fig. 135

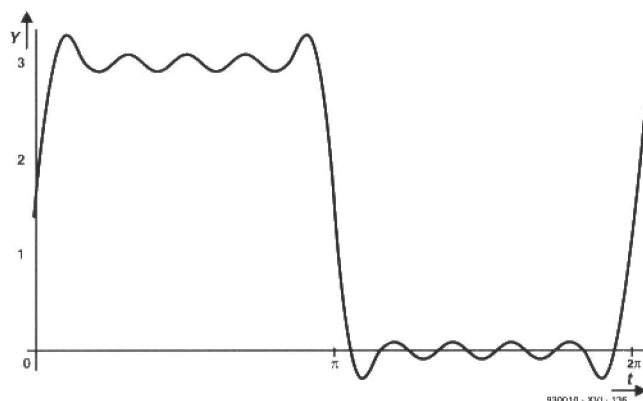


Fig. 136

$$\begin{aligned} a_n &= \frac{1}{\pi} \int_0^\pi 3 \cos nt \, dt + 0 \\ &= \frac{3}{n\pi} [\sin nt]_0^\pi \\ &= \frac{3}{n\pi} [\sin n\pi] = 0.9549 \frac{\sin n\pi}{n} \end{aligned}$$

But $\sin n\pi = 0$ if n is an integer, making $a_n = 0$. This result means that there are no cosine terms. We could have told this at the start because this is essentially an odd function, raised on a d.c. level of 1.5 (compare with **Fig. 134**). The constant term 1.5 simply raises it above the x -axis. If the constant term is ignored, so that, in effect, it is lowered until it passes through the origin, it becomes an odd function and has only sine terms.

Finally, we calculate b_n :

$$\begin{aligned} b_n &= \frac{1}{\pi} \int_0^\pi 3 \sin nt \, dt + 0 \\ &= \frac{-3}{n\pi} [\cos nt]_0^\pi \\ &= \frac{-3}{n\pi} [\cos n\pi - \cos 0] \\ &= \frac{-3}{n\pi} [\cos n\pi - 1] \end{aligned}$$

There are two possibilities to be considered:

- when n is even, $\cos n\pi = 1$, which makes $b_n = 0$;
- when n is odd, $\cos n\pi = -1$, in which event $b_n = 6/n\pi = 1.9099/n$.

The series has only odd cosine terms. This, too, might have been foreseen: when the waveform is shifted down to be symmetrical about the x -axis, it has half-wave inversion, resulting in it having no even terms. Writing out the series:

$$\begin{aligned} y &= 1.5 + 1.9099 \left(\sin t + \frac{\sin 3t}{3} + \right. \\ &\quad \left. + \frac{\sin 5t}{5} + \frac{\sin 7t}{7} + \frac{\sin 9t}{9} + \dots \right) \end{aligned}$$

Figure 136 shows the graph of the series when taken to the 10th harmonic ($n = 9$).

Frequency spectrum

Another way of looking at a series is to plot its frequency spectrum. This has a vertical line for each frequency, the height of the line being proportional to the amplitude of the frequency. In the series we have just calculated, the amplitude of the fundamental is 1.9099. The amplitude of the 1st harmonic is $1.9099/3 = 0.6366$. **Figure 137** shows the plot of the fundamental

and first 10 harmonics. The even ones are missing and the amplitude of the odd ones falls away fairly rapidly. Last month we analysed a sawtooth wave before and after passing it through a high-pass filter. **Figure 138** shows the frequency spectra of these waveforms; the effect of filtering is obvious.

Pulse waveforms

In **Fig. 139** we have a pulse waveform, which is another example of a piecewise function. This is analysed in a similar way to the 1:1 square wave above. If we shift it $\pi/10$ to the left, the pulse begins at $-\pi/10$ and ends at $\pi/10$. It is now an even function, so its Fourier series has no sine terms. By inspection, we can tell that $A_0 = 0.3$.

For the cosine terms:

$$\begin{aligned} a_n &= \frac{1}{\pi} \int_{-\pi/10}^{\pi/10} 3 \cos nt \, dt \\ &= \frac{1}{\pi} \left[\frac{3}{n} \sin nt \right]_{-\pi/10}^{\pi/10} \\ &= \frac{3}{n\pi} \left[\sin \frac{n\pi}{10} - \sin \frac{-n\pi}{10} \right] \\ &= \frac{6}{n\pi} \sin \frac{n\pi}{10} \\ &= 1.9099 \sin \frac{(n\pi/10)}{n} \end{aligned}$$

If $n = 1$, then $\sin(n\pi/10) = 0.3090$; for $n = 2$ to 9, we obtain 0.5878, 0.8090, and so on to 0.3090. When $n = 10$, $\sin(n\pi/10) = 0$, so there is no 9th harmonic. The sequence of values is repeated for $n = 11$ to 20, except that they are negative. From $n = 21$ onwards the whole sequence repeats, but we are not concerned with harmonics of such a high order.

Written out as far as the 2nd harmonic, the series looks like this:

$$\begin{aligned} y &= 0.3 + 1.9099(0.3090 \sin t \\ &\quad + 0.5878 \frac{\sin 2t}{2} \\ &\quad + 0.8090 \frac{\sin 3t}{3} + \dots) \end{aligned}$$

Simplifying the coefficients, by dividing by n (1, 2, 3, ...):

$$\begin{aligned} y &= 0.3 + 1.9099(0.3090 \sin t \\ &\quad + 0.2939 \sin 2t \\ &\quad + 0.2700 \sin 3t + \dots) \end{aligned}$$

The values of $\sin(n\pi/10)$ increase for the first few terms, so this partly offsets the effect of dividing them successively by 1, 2, 3, In consequence, the first few harmonics are almost as strong

as the fundamental as shown in **Fig. 140**. This is plotted as far as the 10th harmonic (there is no 9th). Compared with the square wave of **Fig. 135**, as shown in **Fig. 137**, there is much less fall-off in the lower harmonics of

this pulse wave. This property of pulse waveforms is made use of in synthesizer circuits. A pulse waveform is a strong source of harmonics which can be filtered (formant filtering) to adjust their proportions until the resultant

sound has the timbre of a given musical instrument. Although the amplitude of the higher harmonics falls off more significantly, the limits of audibility are reached around the 5th harmonic. However, there is an increase of amplitude from the 10th to the 14th, which has an amplitude almost equal to that of the 7th harmonic. This illustrates the fact that unexpectedly strong harmonics may be present in pulse signals.

Other periods

The formulae described above all refer to a waveform in which one cycle takes 2π seconds. In other words, the angular velocity is unity. This corresponds to a frequency of 0.159 Hz. This is rather lower than many of the frequencies we meet in electronic circuits and, even though the analysis of different waveforms is independent of the frequency of the fundamental, there are many instances when we want to know the Fourier coefficients for a frequency that is **not** 0.159 Hz. Adapting the formulae to another frequency is just a matter of altering the time-scale.

The equations relating angular velocity, ω , frequency, f , and period (length of cycle), T , are:

$$\omega = 2\pi/T$$

or

$$T = 2\pi/\omega.$$

The phase angle at any given time t is ωt . The Fourier series in these conditions is the same as before, except that we replace t in the cosine and sine terms by ωt . Conversely, making $\omega = 1$ restores the terms to their original form.

The formulae for the constant term is:

$$A_0 = \frac{1}{T} \int_0^T F(t) \, dt$$

The formulae for the coefficients are:

$$a_n = \frac{2}{T} \int_0^T F(t) \cos n\omega t \, dt$$

$$b_n = \frac{2}{T} \int_0^T F(t) \sin n\omega t \, dt$$

These show the limits of integration running from 0 to T , but they can also run from $-T/2$ to $T/2$ if this makes the integration any easier.

We will derive the Fourier series for the square wave of **Fig. 135**, but with a period of

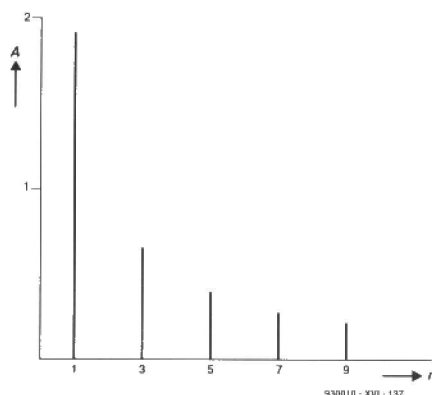


Fig. 137

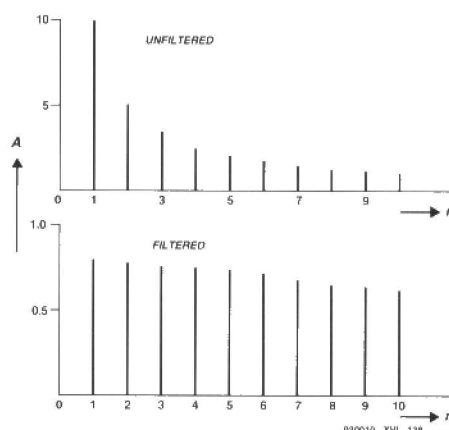


Fig. 138

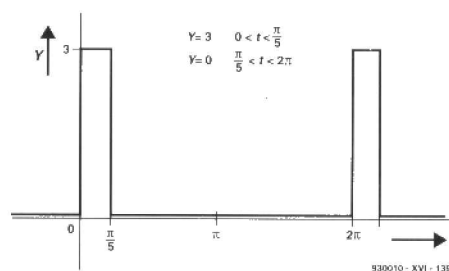


Fig. 139

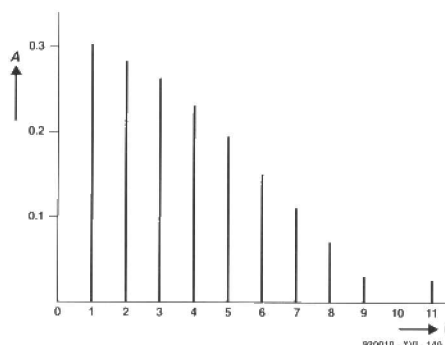
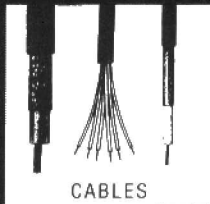


Fig. 140

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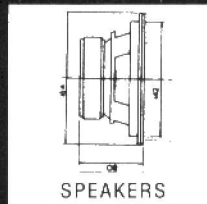
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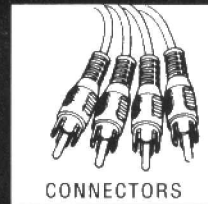
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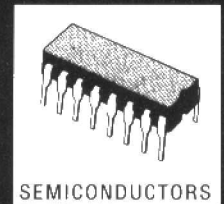
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0.01 s., corresponding to a frequency of 100 Hz. At 100 Hz, $T = 0.001$ and $\omega = 2\pi/0.001 = 628.3$ rad.

The average value of y is not affected by the frequency, so $A_0 = 1.5$ as before. Also, as before, we recognize this to be an odd function, so that $a_n = 0$ and there are no cosine terms. For the sine terms:

$$b_n = \frac{2}{0.01} \int_0^{0.005} 3 \sin n\omega t \, dt$$

$$= \frac{-3}{0.005n\omega} (\cos n\pi - 1)$$

If n is even, $\cos n\pi = 1$, and $b_n = 0$. There are no even terms. If n is odd, $\cos n\pi = -1$ and $b_n = 6/0.005n\omega = 1.9099/n$.

The series is exactly the same as that for the square wave of **Fig. 135**, except that, instead of $\sin t$, $\sin 3t$, ..., we now have $\sin \omega t$, $\sin 3\omega t$, ... The graph of the series has the same shape, except that the scale on the x -axis runs from 0 to 0.001 s. Thus, all that we have said about waveforms with a period of 2π applies with little modification to periods of other lengths.

By contrast with the slow fall-off of harmonics in pulse waveforms, there are other waveforms in which the rate of fall-off is rapid. An example is shown in **Fig. 141**. This is the waveform of a half-wave rectified alternating voltage. The coefficients for the cosine terms are given by

the equation

$$a_n = \frac{2}{\pi(1-n^2)}$$

The denominator contains n^2 and successive coefficients (there are even terms only) are: $2/3\pi$, $2/15\pi$, $2/35\pi$, $2/63\pi$, ... The series

has only a single sine term, so this has no effect on the rapid fall-off of the harmonics.

At this point we leave the discussion of the Fourier Series, having shown how to analyse many of the most commonly occurring waveforms. Often the in-

tegrations are long, and prone to error, especially with the frequent changes in sign that result from integrating functions containing sines and cosines. The rules we have discussed will help by eliminating the need for some of the integrations. When you have arrived at the equation for a series, plotting it with a graphic calculator is a rapid means of checking that it is essentially correct.

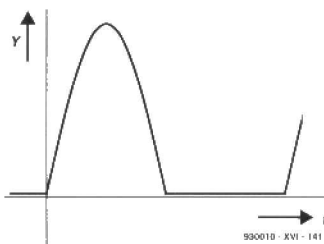


Fig. 141

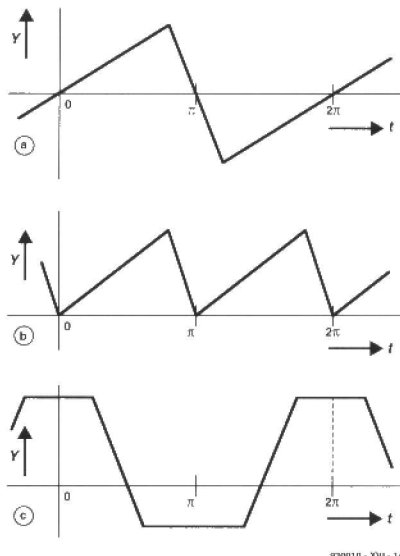


Fig. 142

Test yourself

1. To what categories do the waveforms of **Fig. 142** each belong. In each case state what elements you would expect to find in their Fourier series.
2. A sawtooth waveform with period 2π is defined by these equations:
 $y = 3t \quad 0 < t < \pi$
 $y = 3t - 3\pi \quad \pi < t < 2\pi$
 Derive its Fourier series.

Answers to Test yourself (Part 15)

$a_0 = 2\pi$; $a_n = 0$; $b_n = -4/n$.
Series is: $y = 2\pi - 4\sin t - 2\sin 2t - 1.333\sin 3t - \sin 4t \dots$

Filtered signal is

$$u_{\text{out}} = -3.988\sin(t - 0.0808) - 1.975\sin(2t - 0.1608) - 1.297\sin(3t - 0.2358) - 0.9525\sin(4t - 0.3098) \dots$$

LOW-VOLTAGE MONITOR

Design by J. Ruiter

During experimental work, the power supply is often variable or derived from a mains adaptor. In such cases, it is important to eliminate the risk of damaging ICs through overvoltage. The unit described in this article is intended for monitoring the supply voltage when the standard multimeter is already in use for other purposes.

Although electronic circuits on test should preferably be powered by a supply whose output voltage can be set accurately and is provided with a current limiting facility, in practice this is not always available. If a quickly put together supply is used on the test bench or with experimental work, ideally, two multimeters should be to hand: one for monitoring the supply voltage and the other for carrying out measurements on the circuit. If only one is available, the present monitor may prove useful.

The monitor is suitable for use with voltages in the ranges 2.0–6.0 V, 4.5–5.5 V, 3.0–15.0 V and one set by the user between 0 V and 14 V.

Apart from monitoring direct voltages, the unit may be used to react to sudden changes in voltages. This is, for instance, convenient for checking equipment that has a difficult-to-find, randomly occurring fault. Such equipment may be left operating on the test bench with the monitor attached. If a sudden change in voltage occurs in it, the monitor may indicate this by emitting a squeak from an optional buzzer.

The circuit

The circuit—see **Fig. 1**—is based on two comparators: IC_{1a} and IC_{1b}. These measure the input voltage on terminals A and B against accurately known potentials. These reference voltages are provided by variable zener diode D₁ and potential dividers R₈-P₂, R₉-P₃ and R₂-R₇. The zener voltage can be set accurately to exactly 2.5 V with P₁. Resistor R₁ is the standard series resistor that prevents the zener drawing too large a current.

Divider chain R₂-R₇ provides a number of fixed reference voltages, which are selected by S₁.

Dividers R₈-P₂ and R₉-P₃ provide the (variable) reference voltage that is determined by the user.

If the voltage on terminals A and B rises above, or falls below, set values, D₂ (red) or D₃ (green) lights respectively. If the input voltage lies between two set values, the two diodes light simultaneously. It is also possible to use buzzers as indicators, which eliminates the need to keep

an eye on the LEDs.

The input voltage is also applied to potential divider R₁₀-R₁₁ (1:6). The (scaled down) input voltage is applied to the non-inverting (+) input of IC_{1a} and to the inverting (–) input of IC_{1b}. When the potential at one terminal of the comparators becomes larger or smaller than that at the other input, the relevant comparator changes state. At that instant, the voltage at terminal A is exactly six times the reference voltage applied to the other terminal of the toggling comparator by S₁.

To give a range over which the input voltage may be considered safe, the com-

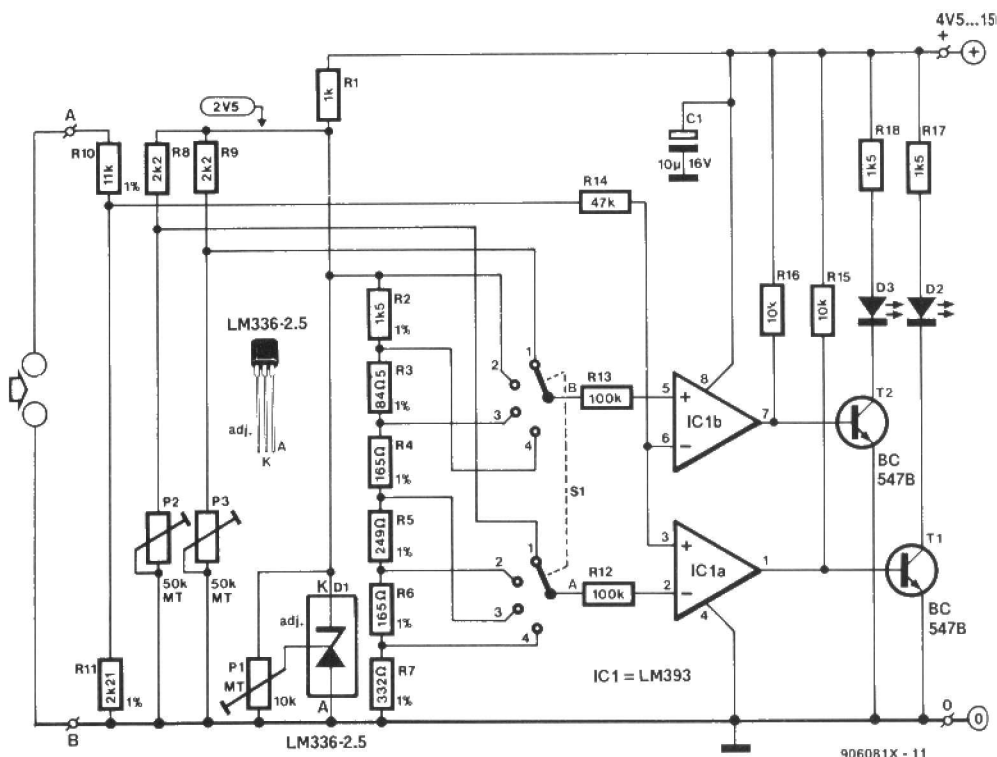
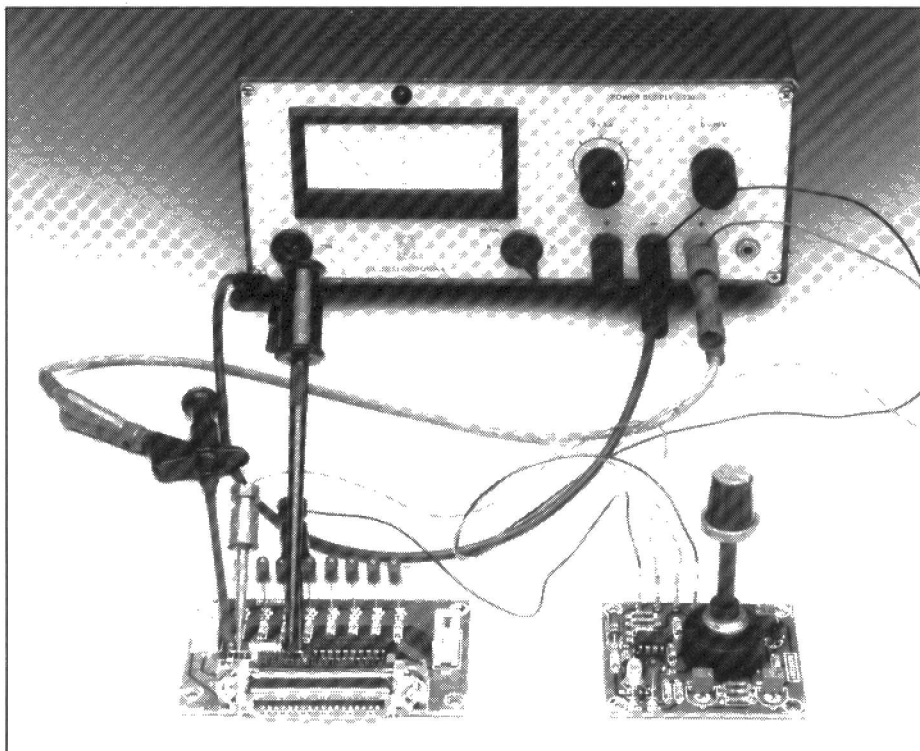
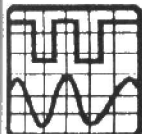
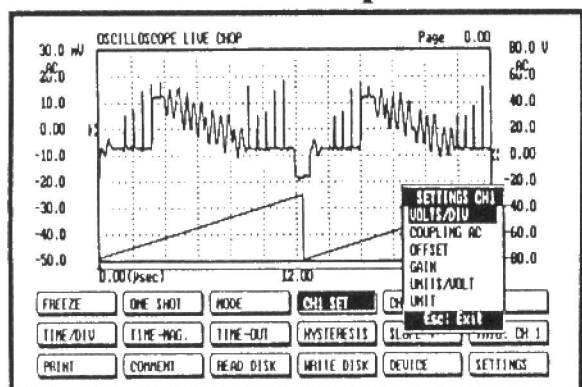


Fig. 1. Circuit diagram of the low-voltage monitor.

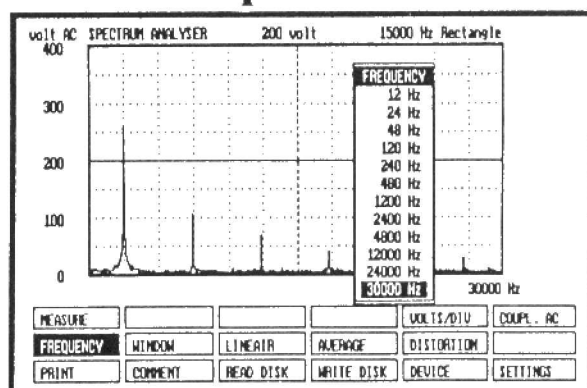


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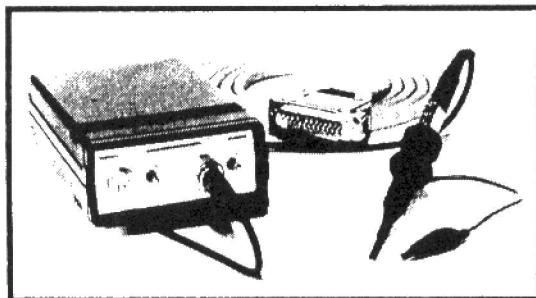
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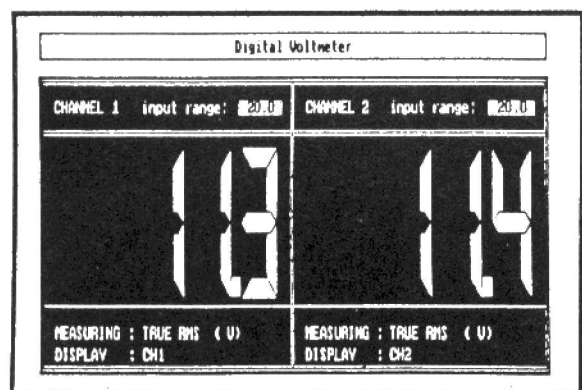
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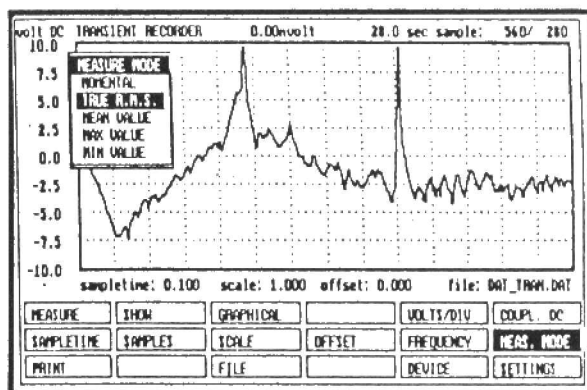
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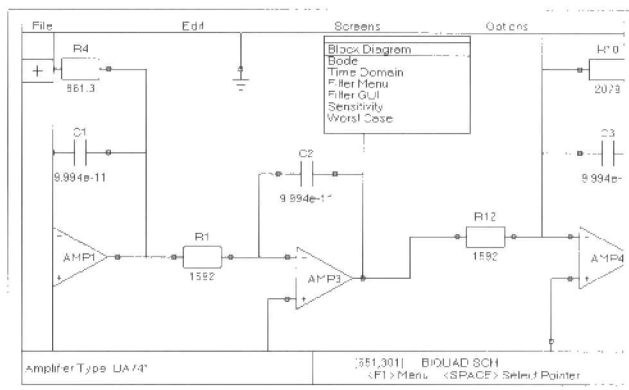
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voltmeter, across D_1 (or P_1). Make sure that the type coding of D_1 is LM336-2.5.

Range 4 is set with a variable power supply, set to the desired voltage, and a voltmeter across input terminals A and B. Adjust P_3 until the green LED just goes out and P_2 until the red LED just goes out.

Finally, make sure that terminal A is clearly marked + and terminal B -. Polarity reversal would not do the comparators any good.

Parts list**Resistors:** $R_1 = 1 \text{ k}\Omega$

$R_2 = 1.5 \text{ k}\Omega$, 1%
 $R_3 = 84.5 \Omega$, 1%
 $R_4, R_6 = 165 \Omega$, 1%
 $R_5 = 249 \Omega$, 1%
 $R_7 = 332 \Omega$, 1%
 $R_8, R_9 = 2.2 \text{ k}\Omega$
 $R_{10} = 11 \text{ k}\Omega$, 1%
 $R_{11} = 2.21 \text{ k}\Omega$, 1%
 $R_{12}, R_{13} = 100 \text{ k}\Omega$
 $R_{14} = 47 \text{ k}\Omega$
 $R_{15}, R_{16} = 10 \text{ k}\Omega$
 $R_{17}, R_{18} = 1.5 \text{ k}\Omega$
 $P_1 = 10 \text{ k}\Omega$, 10 turns preset
 $P_2, P_3 = 50 \text{ k}\Omega$, 10 turns preset

Capacitors: $C_1 = 10 \text{ pF}$, 16 V**Semiconductors:**

$T_1, T_2 = \text{BC547B}$
 $D_1 = \text{LM336-2.5}$
 $D_2 = \text{LED, red}$
 $D_3 = \text{LED, green}$

Integrated circuits: $\text{IC}_1 = \text{LM393}$ **Miscellaneous:**

$S_1 = 2\text{-pole, 6-position rotary switch, with suitable knob}$
Enclosure (if required) 120x65x40 mm ($4\frac{3}{4} \times 2\frac{1}{2} \times 1\frac{1}{2}$ in), e.g. Bopla E430BB – represented in UK by Phoenix Mecano Ltd, telephone (0296) 398 853.

USING THE DOUBLE BALANCED MIXER (DBM)

In radio frequency electronics a mixer is a non-linear circuit or device that permits frequency conversion by the process of heterodyning. Mixers are used in the 'front-end' of the most common form of radio, the superheterodyne (regardless of wave band), in certain electronic instruments and in certain measurement schemes (receiver dynamic range, oscillator phase noise, etc). This article looks at a very popular mixer circuit, the double balanced type.

By Joseph J. Carr, B.Sc., M.S.E.E.

THE block diagram for a basic mixer system is shown in Fig. 1; this diagram is generic in form, but also represents the front-end of superheterodyne radio receivers. The mixer has three ports: F_1 receives a low-level signal, and would correspond to the RF input from the aerial in radio receivers; F_2 is a high-level signal, and corresponds to the local oscillator (LO) in superhet radios; and F_3 is the resultant mixer product (corresponding to the **intermediate frequency** or 'IF' in superhet radios). These frequencies are related by:

$$F_3 = mF_1 \pm nF_2 \quad (1)$$

Where:

F_1 , F_2 and F_3 are as described above;
 m and n are counting numbers (zero plus integers 0, 1, 2, 3, ...)

In any given system, m and n can be zero, or any integer, but in practical circuits it is common to consider only the first, second and third order products. For sake of simplicity, let us consider a first-order circuit ($m=n=1$). Such a mixer would output four frequencies: F_1 , F_2 , $F_{3a} = F_1 + F_2$, and $F_{3b} = F_1 - F_2$. In terms of a radio receiver, these frequencies represent the RF input signal, the local oscillator signal, the **sum IF** and the **difference IF**. In radios, it is common practice to select either sum or difference IF by filtering, and rejecting all others.

There are a number of different types of mixer circuit, but only a few different classes: **single-ended**, **single balanced** (or simply 'balanced') and **double balanced**. Most low-cost superheterodyne radio receivers use single-ended mixers, although a few of the more costly 'communications receiver' models use singly or double balanced mixers for improved performance. This article focusses on the double balanced mixer (DBM) because it offers superior performance over the other forms, but is not as well known in electronic hobby circles.

One of the advantages of the DBM over the other forms of mixer is that it sup-

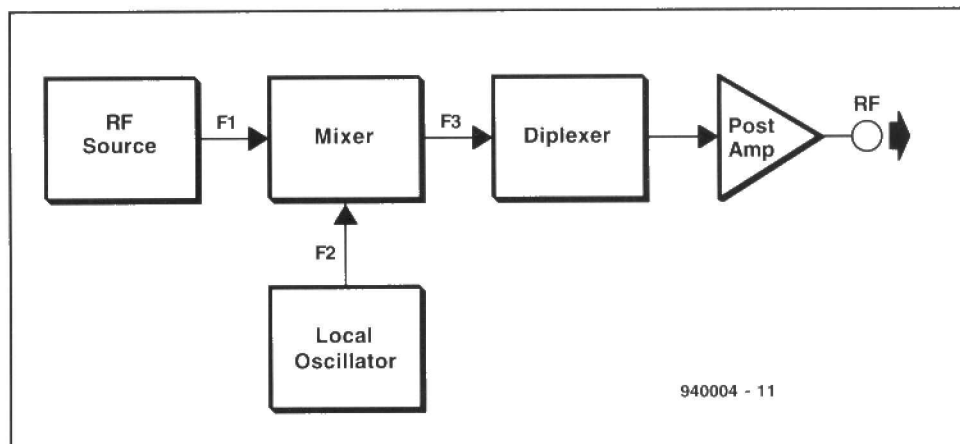


Fig. 1. Block diagram of a mixer used as a frequency converter.

presses F_1 and F_2 components of the output signal, passing only the sum and difference signals. In a radio receiver using a DBM, the IF filtering and amplifier would only have to contend with sum and difference IF frequencies, and not bother with the LO and RF signals. This effect is seen in DBM specifications as the port-

to-port isolation figure, which can reach 30 to 60 dB depending on DBM model.

A **diplexer** stage is shown in Fig. 1, and is used to absorb unwanted mixer products, and pass desired frequencies. These frequency selective circuits are discussed below.

A **post-amplifier** stage is typically

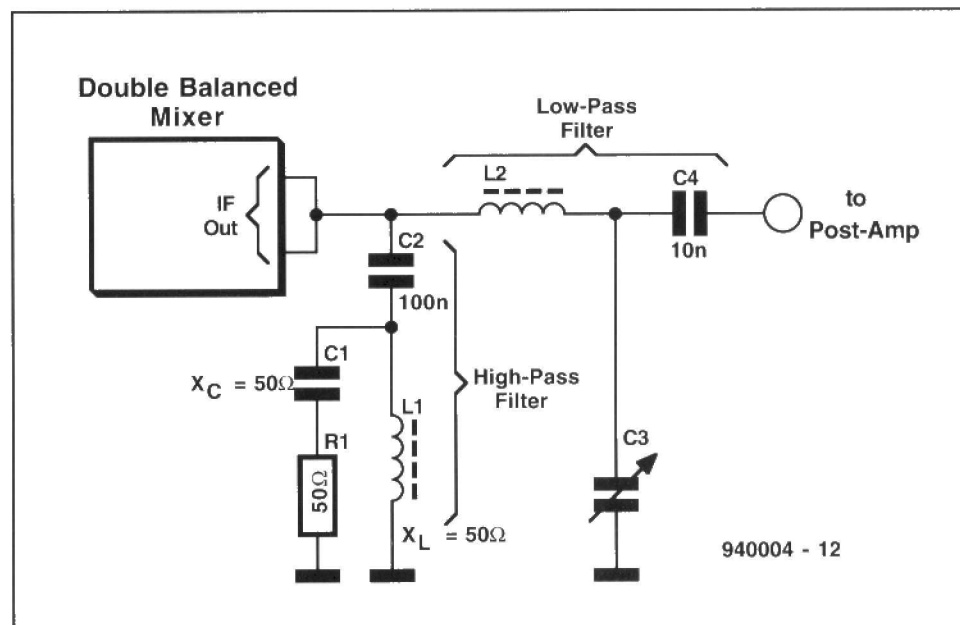


Fig. 2. Diplexer circuit based on low-pass and high-pass filters.

included because the insertion loss of most passive DBMs is considerable (5 to 12 dB). The purpose of the amplifier is to make up for the loss of signal level in the mixing process. Some active DBMs, incidentally, have a **conversion gain** figure, not a loss. For example, the popular **Signetics** NE602 device offers 20 dB of conversion gain.¹

Diplexer circuits

The RF mixer is like most RF circuits in that it wants to be terminated in its characteristic impedance. Otherwise, a standing wave ratio (SWR) problem will result, causing signal loss and other problems. In addition, certain passive DBMs (of which, more below) will not work well if improperly terminated. A number of different diplexer circuits are known, but two of the most popular are shown in **Figs. 2** and **3**.

A diplexer has two jobs: 1) it absorbs undesired mixer output signals, so they are not reflected back into the mixer, and 2) it transmits desired signals to the output. In **Fig. 2**, these goals are met with two different LC networks; a high-pass filter and a low-pass filter. The assumption in this circuit is that the difference IF is desired, so a high-pass filter with a cut-off above the difference IF is used to shunt the sum IF (plus and LO and RF signals that survived the DBM process) to a dummy load (R_1). The dummy load shown in **Fig. 2** is set to 50 Ω because that is the most common system impedance for RF circuits (in practice, a 51- Ω resistor might be used). The dummy load resistor can be a 1/4-watt unit in most low-level cases, but regardless of power level it must be a noninductive type (e.g. carbon composition or metal film).

The inductor (L_1) and capacitor (C_1) values in the high pass filter are designed to have a 50- Ω reactance at the IF frequency. These values can be calculated from:

$$L = \frac{50\Omega}{2\pi F_3} \quad (2)$$

$$C = \frac{1}{2\pi F_3 (50\Omega)} \quad (3)$$

Where L is in henrys, C is in farads, and F_3 is in hertz.

The low-pass filter transmits the desired difference IF frequency to the output, rejecting everything else. Like the high-pass filter, the L and C elements of this filter are designed to have reactances of 50 Ω at the difference IF frequency.

Recently I built a sweep generator to facilitate an high performance AM band (540-1700 KHz) receiver that I am designing. The sweeper circuit is a varactor tuned VCO driven with a 45-Hz sawtooth wave. The swept oscillator is heterodyned against a 14-MHz crystal oscilla-

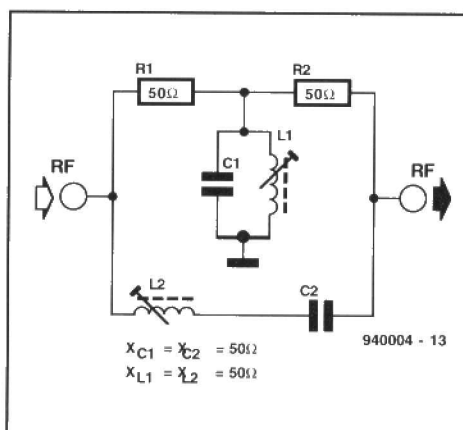


Fig. 3. Diplexer circuit based on series and parallel resonant circuits.

tor, producing difference frequencies which can be tuned to either 455 KHz (my selected IF), or any frequency in the AM band. My diplexer unit consists of two 3,000-KHz Butterworth filters, one high-pass and the other low-pass; each filter consists of five reactance elements. The high-pass filter was terminated in a 50- Ω dummy load made by paralleling two 100- Ω metal film resistors (which were hand-selected for the correct value). The low-pass filter was terminated in a post amplifier with a 50- Ω input impedance.

Another popular diplexer circuit is shown in **Fig. 3**. This circuit consists of a parallel resonant 50- Ω tank circuit (C_1 , L_1), and a series resonant 50- Ω tank circuit (C_2 , L_2). The series resonant circuit passes its resonant frequency while rejecting all others because its impedance is low at resonance and high at other frequencies. Alternatively, the parallel resonant tank circuit offers a high impedance to its resonant frequency, and a low impedance to all other frequencies.

Because C_1 - L_1 are shunted across the signal line, it will short out all but the resonant frequency.

In direct conversion receivers, a mixer is used to down convert CW and SSB signals directly to audio by setting F_2 close to F_1 , without using an IF amplifier chain. In those receivers it is common practice to build a diplexer similar to **Fig. 4**. Capacitor C_1 passes high frequencies (which are RF), and they are absorbed in a 50- Ω dummy load. The low-frequency audio signals (300 to 3,000 Hz) are passed by a 50- Ω low-pass filter consisting of L_1 , L_2 , L_3 , R_2 and C_2 .

JFET and MOSFET DBMs

Junction field effect transistors (JFETs) and metal oxide field effect transistors (MOSFETs) can be arranged in a ring circuit that provides good double balanced mixer operation. **Figure 5** shows a circuit that is based on JFET devices. Although discrete JFETs such as MPF102 or its equivalents can be used in this circuit with success, performance is generally better if the devices are matched, or are part of a single IC device (e.g., the U350 IC). With due attention to layout and input/output balancing, the circuit is capable of better than 30 dB port-to-port isolation over an octave (2:1) frequency change.

The inputs and output of this circuit are based on broadband RF transformers. These transformers are bifilar and trifilar wound on toroidal cores. The input circuit consists of two bifilar wound impedance transformers (Tr_1 and Tr_2). The LO and output circuits are trifilar wound RF transformers. Part of the output circuit includes a pair of low-pass filters which also serve to transform the 1.5 to 2 k Ω impedance of the JFET de-

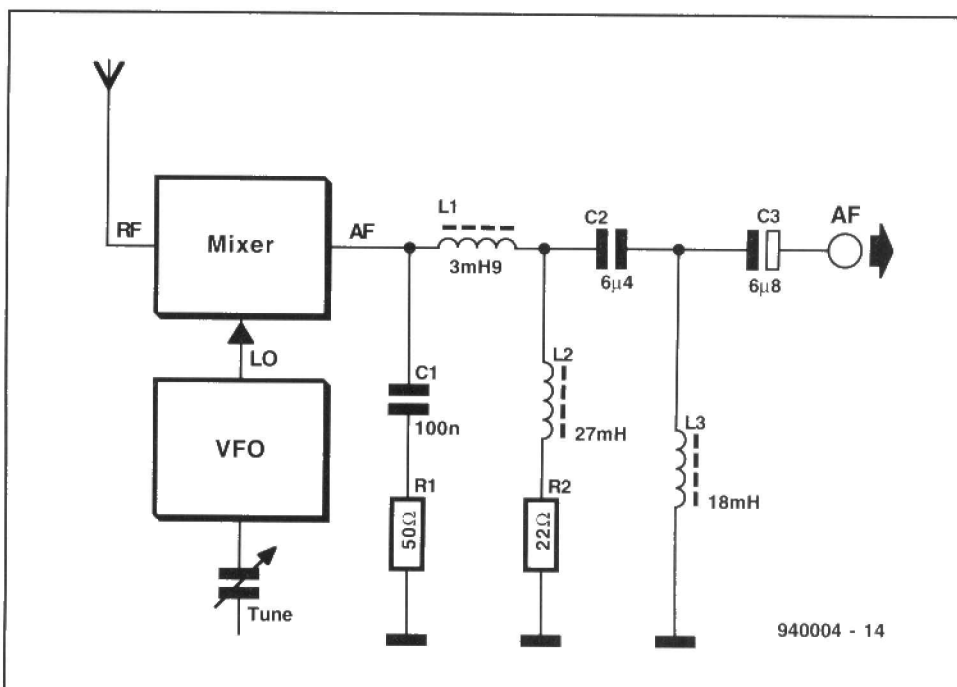


Fig. 4. Diplexer for a direct conversion receiver. Note: R_2 changed to 50 ohms if L_2 is ideal.

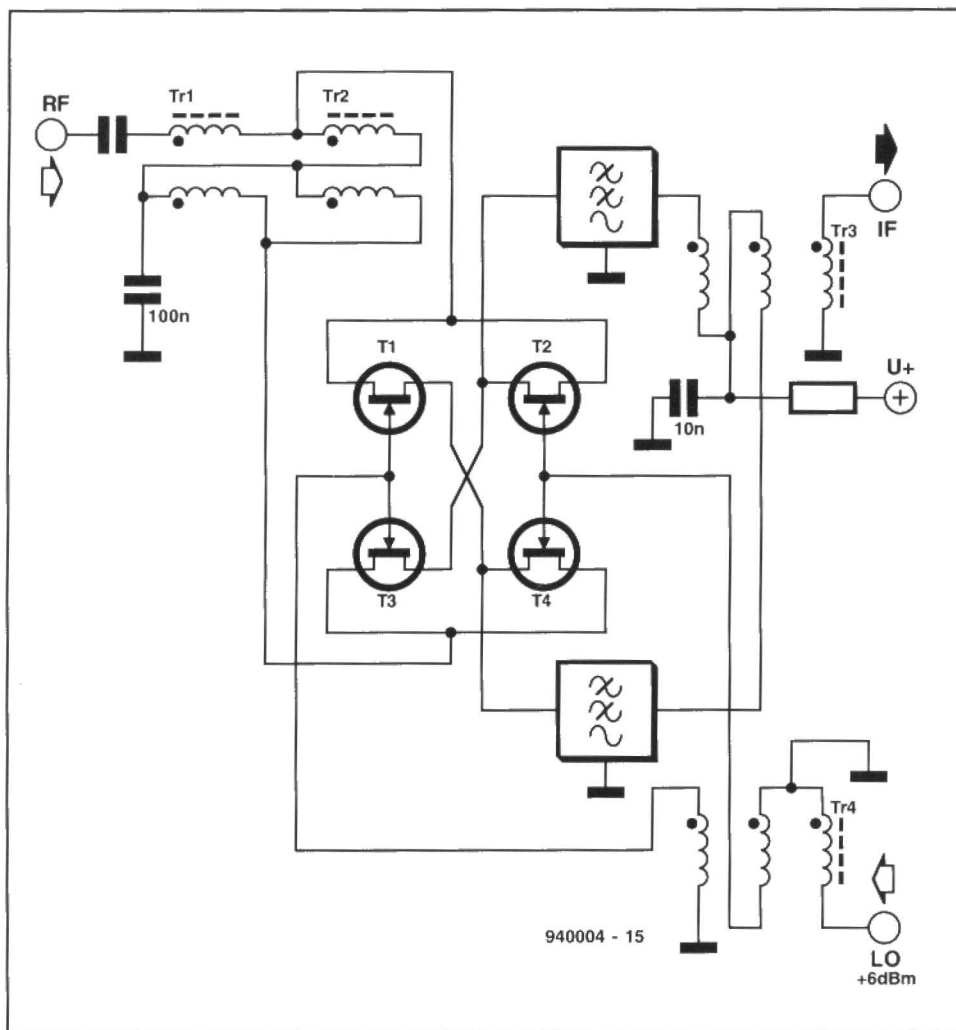


Fig. 5. DBM circuit based on JFET transistors.

vices to 50 Ω . As a result of the needed impedance transformation, the filters must be designed with different R_{in} and R_{out} characteristics, and that fact complicates the use of look-up tables (which would be permitted if the input and output resistances were equal).

Double balanced diode mixer circuits

One of the most easily realized double balanced circuits, whether homebrew or commercial, is the circuit of Fig. 6. This circuit uses a diode ring mixer and balanced input, output and LO ports. It is capable of 30 to 60 dB of port-to-port isolation, yet is reasonably well-behaved in

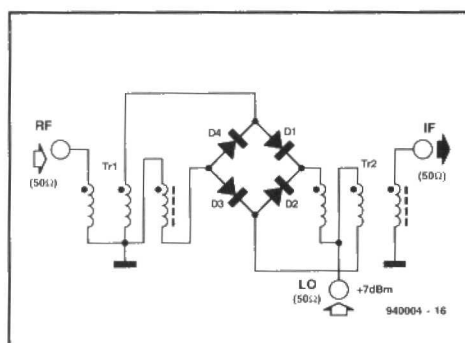


Fig. 6. Diode double balanced mixer.

practical circuits. DBMs such as Fig. 6 have been used by electronic hobbyists and radio amateurs in a wide variety of projects from direct conversion receivers to single sideband transmitters and high-performance shortwave receivers. With proper design, a single DBM can be made to operate over an extremely wide frequency range; several models claim operation from 1 to 500 MHz, with IF outputs from d.c. to 500 MHz.

The diodes (D_1 through D_4) can be ordinary silicon VHF/UHF diodes such as 1N914 or 1N4148. However, superior performance is expected when Schottky hot-carrier diodes, such as 1N5820 through 1N5822 are used instead. Whatever diode is selected, all four devices should be matched. The best matching of silicon diodes is achieved by comparison on a curve tracer, but failing that there should at least be a matched forward/reverse resistance reading. Schottky hot-carrier diodes can be matched by ensuring that the selected diodes have the same forward voltage drop when biased to a forward current of 5 to 10 mA.

Figure 7a shows the internal circuitry for a very popular commercial diode DBM device, the Mini-Circuits SRA-1 and SBL-1 series; a typical SRA/SBL package is shown in Fig. 7b.

These devices offer good performance, and are widely available to hobbyists and radio amateur builders. Some parts houses sell them at retail, as does **Mini-Circuits** [P.O. Box 166, Brooklyn, NY, 11235, USA; phone 714-934-4500]². I do not know the amount of their minimum order, but I have had **Mini-Circuits** in the USA respond to \$25 orders on several occasions ... which is certainly more reasonable than other companies.

The packages for the SRA/SBL devices are similar, being of the order of 20 mm long with 5-mm pin spacing. The principal difference between the packages for SRA and SBL devices is in the height. In these packages, pin no. 1 is denoted by a blue bead insulator around the pin. Other pins are connected to the case or have a green (or other colour) bead insulator. Also, the 'MCL' logo on the top can be used to locate pin 1: the 'M' of the logo is directly over pin 1. **Table 1** shows the characteristics of several DBMs in the SRA and SBL series, while **Table 2** shows the pin assignments for the same devices.

In the standard series of devices, the RF input can accommodate signals up to +1 dBm (1.26 mW into 50 Ω), while the LO input must see a +7 dBm (5-mW) signal level for proper operation. Given the 50- Ω input impedance of all ports of the SRA/SBL devices, the RF signal level must be kept below 700 mV_{pp}, while the LO wants to see 1400 mV_{pp}. It is essential that the LO level be maintained across the band of interest, or else mixing operation will suffer. Although the device will work down to +5 dBm, a great increase in spurious output and less port-to-port isolation is found. Spectrum analyzer plots of the output signal at low LO drive levels show considerable second and third-order distortion products.

Note the IF output of the SRA/SBL de-

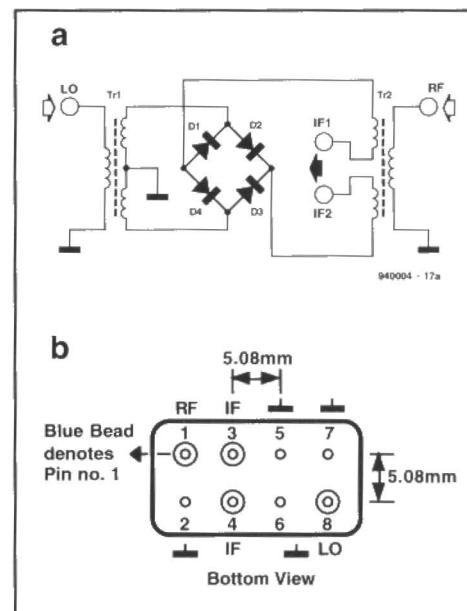


Fig. 7. (a) Mini-Circuits SRA/SBL series DBMs; (b) typical Mini-Circuits DBM package.

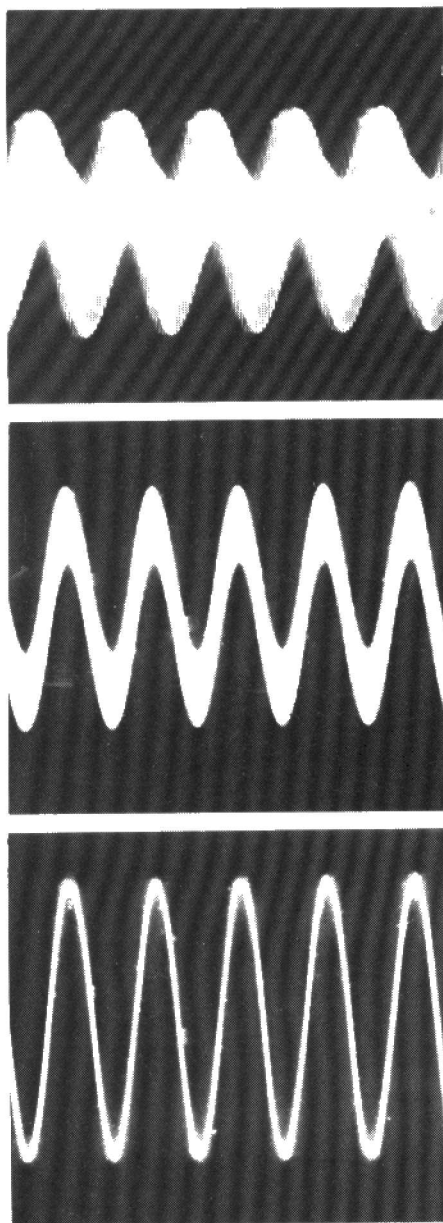


Fig. 8. Waveforms from a circuit using the Mini-Circuits DBM: (a) improperly terminated; (b) with part of diplexer disconnected; (c) output waveform when diplexer is connected.

vices. Although some models in the series use a single IF output pin, most of these devices use two pins (3 and 4), and these **must** be connected together externally for the device to work.

As is true with most DBMs, and all diode ring DBM circuits, the SRA/SBL devices are sensitive to the load impedance at the IF output. Good mixing, and freedom from the LO/RF feedthrough problem, occurs when the mixer looks into a low-VSWR load. For this reason, a good diplexer circuit is required at the output. In experiments, I have found that unterminated SBL-1-1 mixers produce nearly linear mixing when not properly terminated...and that is not what is desired in a frequency converter.

The effects of the termination impedance on the operation of the diode DBM circuit are shown in Fig. 8. The oscilloscope photo in Fig. 8a shows the mixer

Type No.	LO/RF (MHz)	IF (MHz)	Mid-Band Loss (dB)
SRA-1	0.5-500	DC-500	5.5-7.0
SRA-1TX	0.5-500	DC-500	5.5-7.0
SRA-1W	1-750	DC-750	5.5-7.5
SRA-1-1	0.1-500	DC-500	5.5-7.5
SRA-2	1-1000	0.5-500	5.5-7.5
SBL-1	1-500	DC-500	5.5-7.0
SBL-1X	10-1000	5-500	6.0-7.5
SBL-1Z	10-1000	DC-500	6.5-7.5
SBL-1-1	0.1-400	DC-400	5.5-7.0
SBL-3	0.025-200	DC-200	5.5-7.5

Table 1. Main specifications of some commonly found diode double balanced mixers.

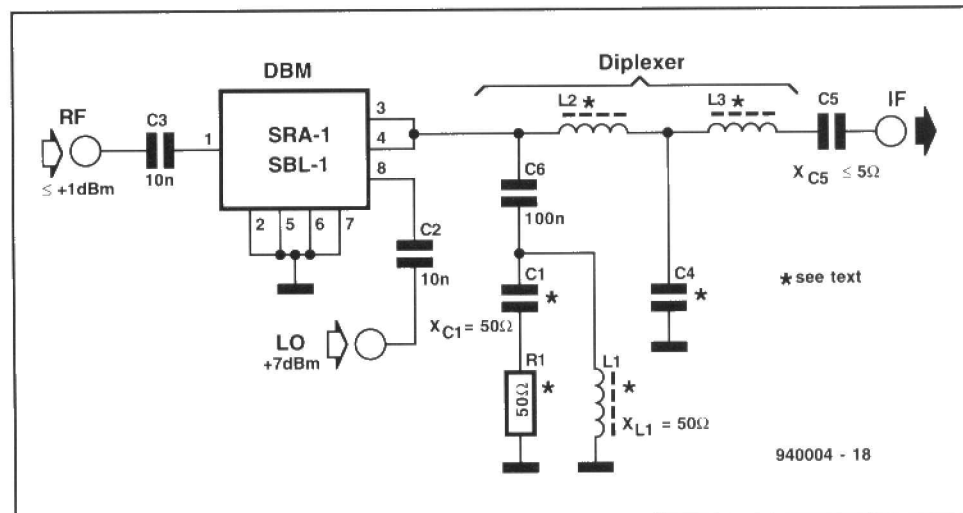


Fig. 9. Typical circuit using the Mini-Circuits SRA/SBL devices.

output directly at pins 3 and 4 of an SBL-1-1. Note that it is a complex waveform of mixed signals, and reflects the fact that the mixer is not properly terminated. The waveform at Fig. 8b was taken at the output of the low-pass filter when the high-pass filter and its associated dummy load was disconnected. At Fig. 8c is the resultant when properly matched high pass (and dummy load) and low pass filters were in operation. The waveform was a nearly clean sine wave of 455 KHz. Another waveform, not shown, was obtained when there was no high pass filter, but the DBM was terminated in a resistance matched to its char-

acteristic impedance and a low pass filter. It was a distorted sinewave, and reflected the fact that other products were present in the output signal.

Figure 9 shows a typical SRA/SBL circuit: RF drive ($\leq +1$ dBm) is applied to pin 1, and the +7 dBm LO signal is applied to pin 8. The IF signal is output through pins 3 and 4, which are strapped together. All other pins (2, 5, 6 and 7) are grounded.

The diplexer circuit consists of a high-pass filter (C_1-L_1) terminated into a $50\text{-}\Omega$ dummy load for the unwanted frequencies, and a low-pass filter ($L_2-L_3-C_4$) for the desired frequencies. All capacitors

Type	LO	RF	IF	GND	Case GND
SRA-1	8	1	3,4	2,5,6,7	2
SRA-1TX	8	1	3,4	2,5,6,7	2
SRA-1-1	8	1	3,4	2,5,6,7	2
SRA-1W	8	1	3,4	2,5,6,7	2,5,6,7
SRA-2	8	3,4	1	2,5,6,7	2,5,6,7
SRA-3	8	1	3,4	2,5,6,7	2
SBL-1	8	1	3,4	2,5,6,7	—
SBL-1-1	8	1	3,4	2,5,6,7	—
SBL-3	8	1	3,4	2,5,6,7	—

Table 2. Pin function overview for diode DBMs.

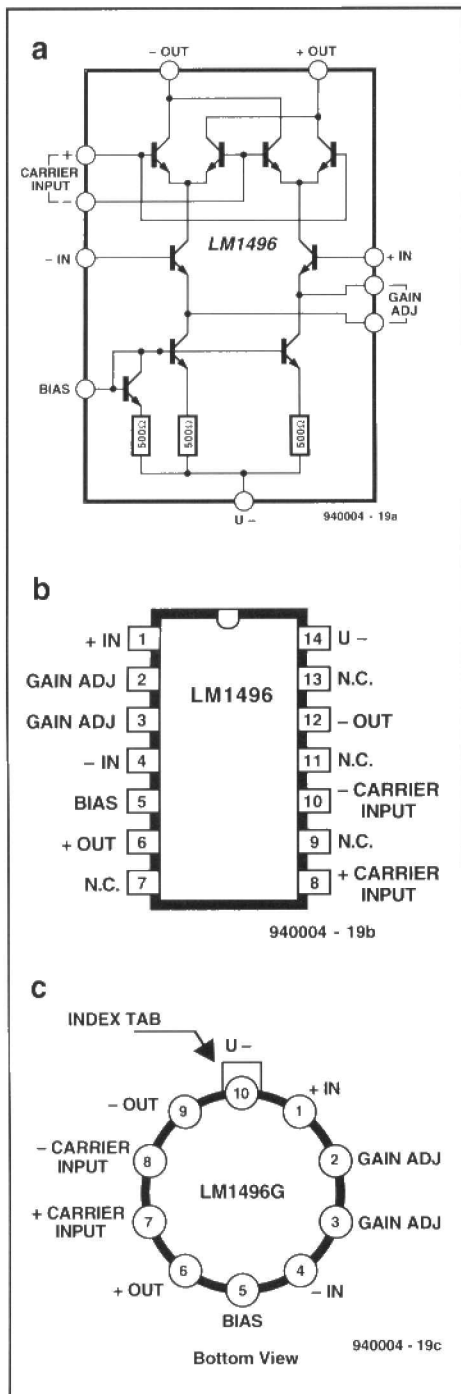


Fig. 10. (a) Internal circuitry for the LM1496 DBM; (b) DIP package for the LM1496; (c) metal can package for the LM1496.

and inductors are selected to have a reactance of $50\ \Omega$ at the IF frequency.

Sometimes 1-dB resistor π -pad attenuators are used at the inputs and the IF output of the DBM. In some cases, the input attenuators are needed to prevent overload of the DBM (overload causes spurious product frequencies to be generated, and may cause destruction of the device). In other cases, the circuit designer is attempting to 'swamp out' the effects of source or load impedance variations. Although this method works, it is better to design the circuit to be insensitive to such fluctuations, rather than to use a swamping attenuator. The reason is that the resistive attenuator causes a signal loss and adds to the noise gener-

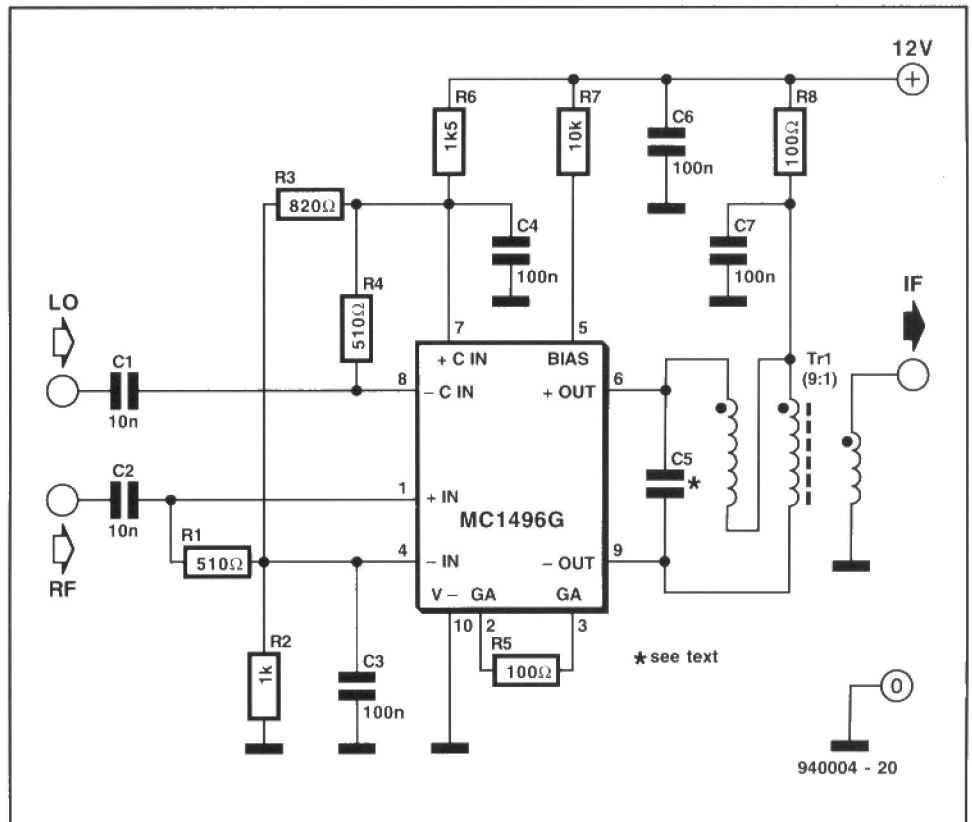


Fig. 11. Mixer circuit using the LM1496.

ated in the circuit (no resistor can be totally noise free). A good alternative is to use a stable amplifier with $50\ \Omega$ input and output impedances, and that is not itself sensitive to impedance variation, to isolate the DBM.

Mini-Circuits devices related to the SRA-1 and SBL-1 incorporate MAR-x series MMIC amplifiers internal to the DBM. One series of devices places the amplifier in the LO circuit, so that much lower levels of LO signal will provide proper mixing. Another series places the amplifier in the IF output port. This amplifier accomplishes two things: it makes up for the inherent loss of the mixer and it provides greater freedom from load variations that can affect the regular SRA/SBL devices.

Bipolar transconductance cell DBMs

Active mixers made from bipolar silicon transistors formed into Gilbert transconductance cell circuits are also easily available. Perhaps the two most common devices are the **Signetics** NE602 device and the LM1496 device (**Maplin** catalogue no. QH47B, p. 463 in 1993 edition).

The NE602 was discussed extensively in Ref. 1, to which the reader is referred for details on input, output and LO configurations.

The LM1496 device is shown in Figs. 10a, 10b and 10c. Figure 10a shows the internal circuitry, while Figs. 10b and 10c show the DIP and metal can packages, respectively. Pins 7 and 8 form the local oscillator (or 'carrier'

in communications terminology) input, while pins 1 and 4 form the RF input. These push-pull inputs are also sometimes labelled 'high level signal' (7 and 8) and 'low level signal' (1 and 4) inputs. D.c. bias (pin 5) and gain adjustment (pins 2 and 3) are also provided.

Figure 11 shows the basic LM1496 mixer circuit in which the RF and carrier inputs are connected in the single-ended configuration. The respective signals are applied to the input pins through d.c. blocking capacitors C_1 and C_2 ; the alternate pin inputs in both cases are bypassed to ground through capacitors C_3 and C_4 .

The output network consists of a 9:1 broadband RF transformer that combines the two outputs, and reduces their impedance to $50\ \Omega$. The primary of the transformer is resonated to the IF frequency by capacitor C_5 .

Figure 12 shows a circuit that uses the LM1496 device to generate double sideband suppressed carrier (DSSC) signals. When followed by a 2.5 to 3-KHz bandpass filter, which is off-set from the IF frequency, this circuit will also generate single sideband (SSB) signals. In common practice, a crystal oscillator will generate the carrier signal (U_c), while the audio stages produce the modulating signal (U_m) from an audio oscillator or microphone input stage. I once saw a circuit that is very similar to this one in a signal generator/test set used to service both amateur radio and marine HF-SSB radio transceivers. It was the signal source to test the receiver sections of the transceivers. The carrier was set to

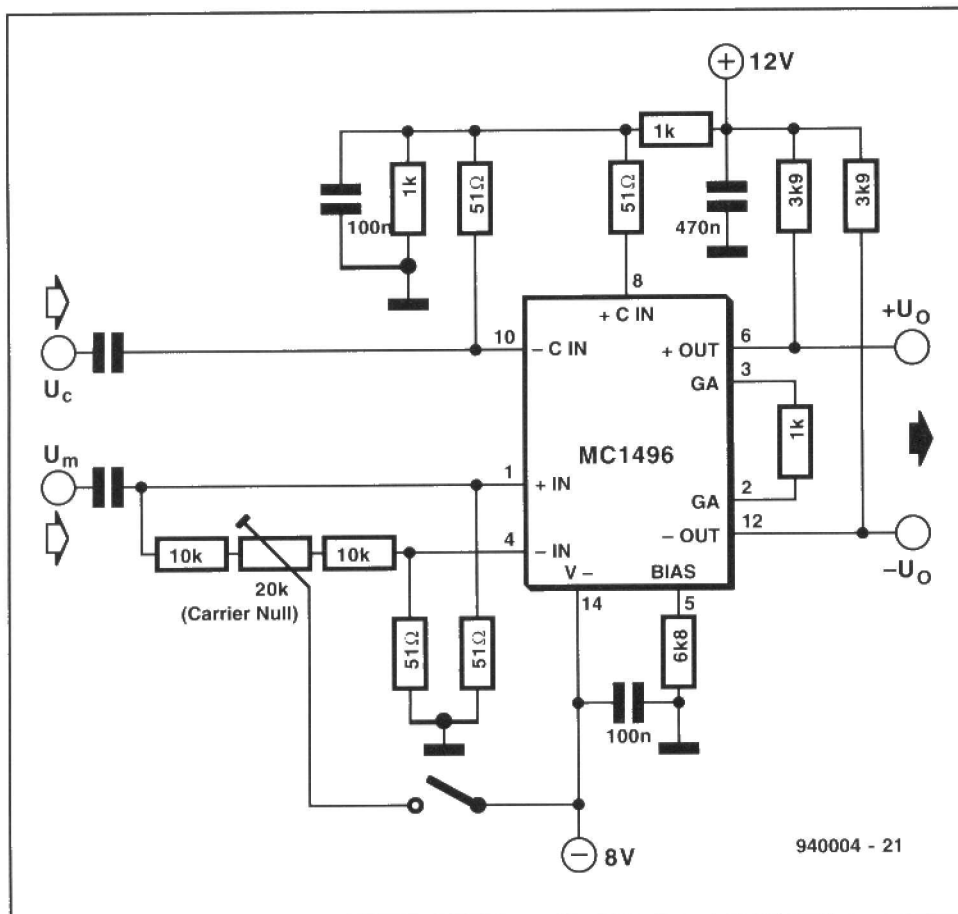


Fig. 12. Double sideband suppressed carrier (DSSC) generator circuit using the LM1496.

9 MHz, and both lower sideband (LSB) and upper sideband (USB) **KVG** crystal filters were used to select the desired sideband. An alternate scheme which is cheaper uses a single 9-MHz crystal filter, but two different crystals at frequencies either side of the crystal passband. One crystal would generate the USB signal, while the other would generate the

LSB signal.

For single sideband to be useful it has to be demodulated to recover the audio modulation. The circuit of **Fig. 13** will do that job nicely. It uses an LM1496 DBM as a **product detector**. This type of detector works on CW, SSB and DSB signals (all three require a local oscillator injection signal), and produces the audio

resultant from heterodyning the local carrier signal against the SSB IF signal in the receiver. All SSB receivers use some form of product detector at the end of the IF chain, and many of them use the LM1496 device in a circuit similar to **Fig. 13**.

Conclusion

Double balanced mixer circuits work better than most other mixer circuits in radio receivers, SSB transmitters/receivers, instrumentation and measurement situations. They are easy to use in most cases, and if properly designed into a circuit yield good results with minimum effort. ■

References:

1. 'NE602 primer', Joseph J. Carr, *Elektor Electronics* January 1992, pp. 20-25.
2. In the UK, contact Dale Electronics Ltd., Camberley, Surrey, tel. (025) 28 35094.

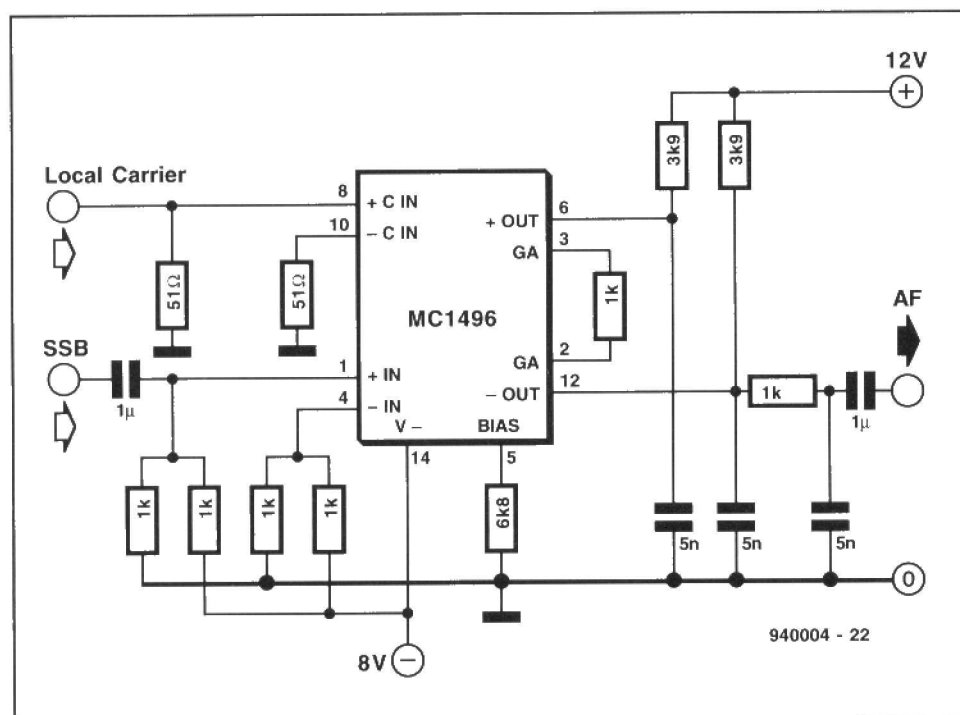


Fig. 13. Single-sideband/CW product detector for receiver using the LM1496.



Although huge monitors are quite common in today's party bunkers, clubs and discotheques, the idea of using a TV set instead of the more usual set of coloured lamps is quite novel. Here, a circuit is described to produce playful light effects on the telly.

From an idea by B. Willaert

THE TV sound-to light unit described in this article may be driven with a line signal or a signal picked up by a microphone. Depending on the spectral composition of the input signal (bass, mid-range, treble), the circuit sends a signal to the red, green or blue (R, G, B) input on the SCART socket of a TV set. This causes the TV screen to go red, green or blue, or blends of these primary colours if the input signal contains two or three strong components in the respective frequency ranges. This means that the operation of the TV sound-to-light unit is, in principle, identical to that of a 'conventional' unit with three lamps. As an unusual feature, however, the present unit enables colours to be mixed.

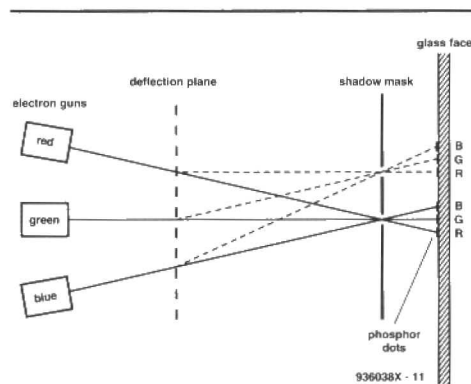


Fig. 1. The perceived colour of a picture element is created by blending the primary colours, red, green and blue, at the right ratio. The correct colour is obtained by firing electrons at phosphor particles at the inside of the picture tube.

Television: the basics

Before looking at the design of the TV sound-to-light unit, a brief recap is given of the operation of the TV system. The screen of a colour TV may be compared with a painter's palette with only the three primary colours on it: red (R), green (G) and blue (B). Any colour can be made by mixing the RGB components at certain ratios.

A TV set obviously does not use paint to mix colours. Instead, the primary colours are mixed using electron beams. The principle is illustrated in Fig. 1. Each primary colour has its own electron gun which 'fires' a very narrow beam in the direction of the inside surface of the TV picture. The three beams converge at the so-called shadow mask at the inside of the picture tube. The mask is a thin plate with masses of small holes which pass the three beams. When the beams leave the holes in the shadow mask, they arrive on a layer of phosphor particles which covers the inside of the picture tube. Each beam 'hits' its own phosphor type. The phosphor particles light up when 'bombarded' with electrons, and so visualize the colours red, green and blue.

Since the three tiny light spots in each pixel are very close together, the viewer perceives a dot with a certain colour blend rather than three individual primary colours. In this way, each picture element ('pixel') is provided with the correct colour information, and the entire picture is built up pixel-by-pixel.

The received TV signal contains, among others, information on the mixture ratio of the R, G and B signals. This information is received in compacted form, and decoded inside the TV set to yield the three primary colours. Most modern TV sets have a SCART socket (also called Peritel or Euro A/V), which allows the RGB amplifiers and associated electron guns in the set to be driven with external signals. And that, you guessed it, is exactly what the present circuit does.

Block diagram

The basic structure of the TV sound-to-light unit is shown in Fig. 2. As with an 'ordinary' sound-to-light unit, the input signal is obtained either from a 'line' connection (say, the mixing console output) or a microphone. The sensitivity of the circuit is adjustable by setting the gain of the input amplifier.

The amplified audio signal is fed to three filter sections: a low-pass filter, a band-pass filter and a high-pass filter. These filters extract the bass, mid-range and treble information from the input signal. The filter output signals

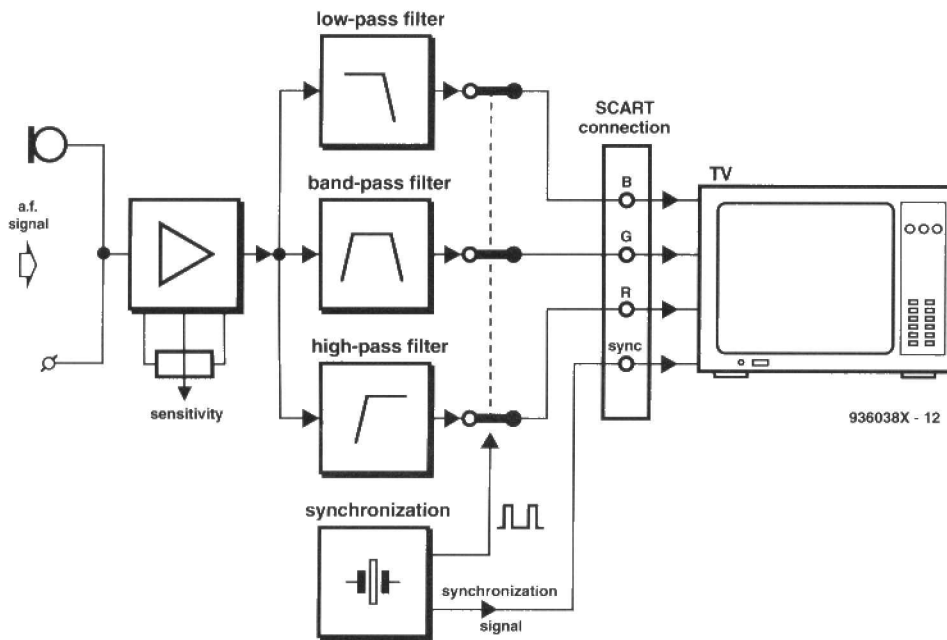


Fig. 2. Most functions of the TV sound-to-light unit may be found in any conventional sound-to-light unit based on lamps. The difference, however, is the TV interface, which consists of RGB driver stages and a synchronisation control circuit.

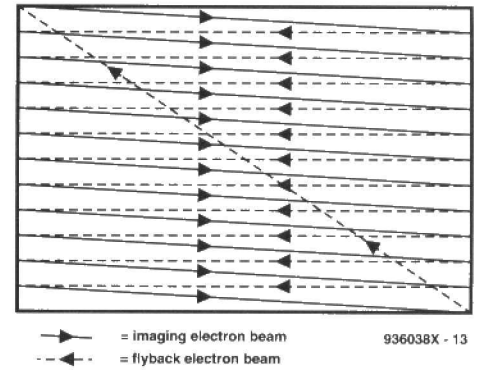


Fig. 3. The flyback (retrace) beam is quenched to avoid unwanted horizontal and diagonal lines on the TV screen.

then drive the RGB inputs of the TV. Low frequencies cause the screen to go red, while mid-range and high components turn it green or blue respectively.

The block diagram also shows a synchronisation sub-circuit. This serves to ensure that every picture line has the right length (approx. 64 μ s), and that the retrace (or 'flyback') beam is

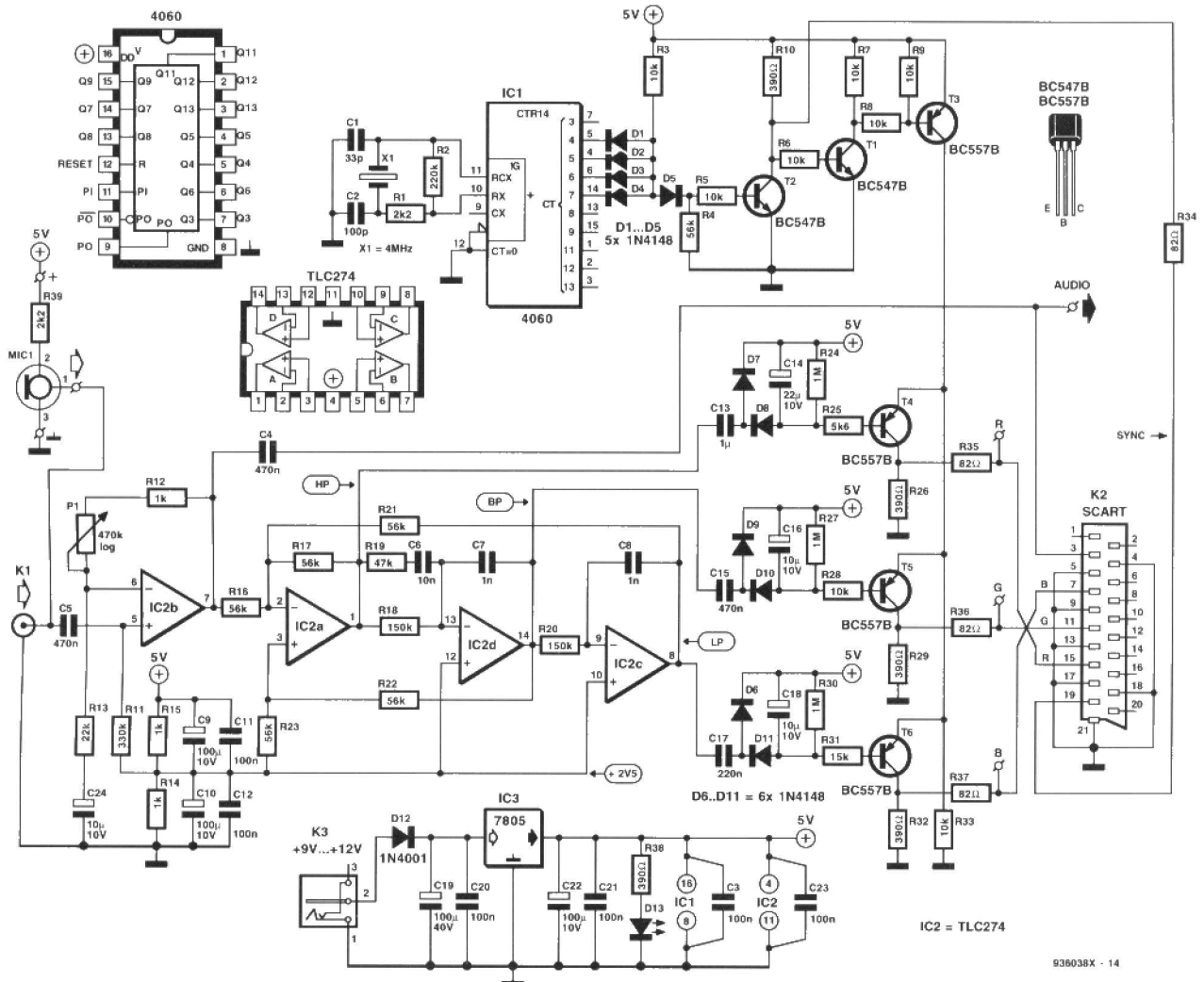


Fig. 4. Circuit diagram of the TV sound-to-light unit. The circuit takes its input signal either from a microphone or a line connection. A crystal oscillator is used to ensure the correct picture line length of 64 μ s (including the synchronisation pulse).

quenched. As illustrated in **Fig. 3**, the electron beam makes a scanning movement across the screen. During the retrace period, the beam is quenched (switched off) to avoid unwanted lines, both horizontally and diagonally, being written on to the screen.

Practical circuit

Although the circuit diagram in **Fig. 4**

looks complex at first glance, the functions of the various sub-circuits are easily recognized from the block diagram discussed above.

The audio signal is picked up by microphone Mic_1 , and fed to the input of a simple preamplifier stage based on opamp IC_{2b} . Alternatively, the input signal may be applied directly via 'line' socket K_1 . The amplification of IC_{2b} may be set to a value between 0.02 and

20. The preamplifier output signal is applied to a combined filter, which divides the signal into low, mid-range and high components. The high frequencies leave the filter via pin 1 of IC_{2a} . The mid-range signals are found at pin 14 of IC_{2d} , and the low frequencies, at pin 8 of IC_{2c} .

Next, the three components are applied to three identical drivers, T_4 , T_5 and T_6 . Each signal is first rectified

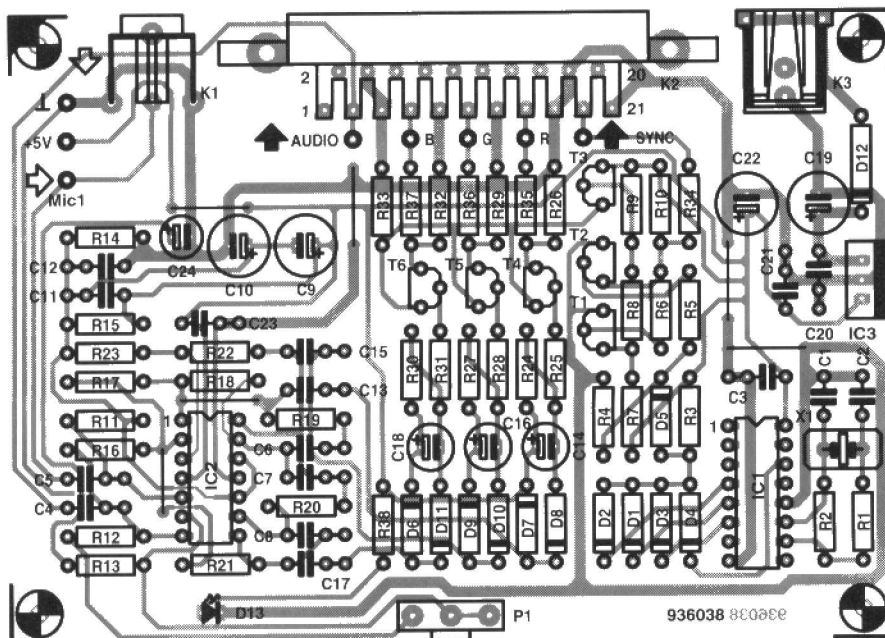
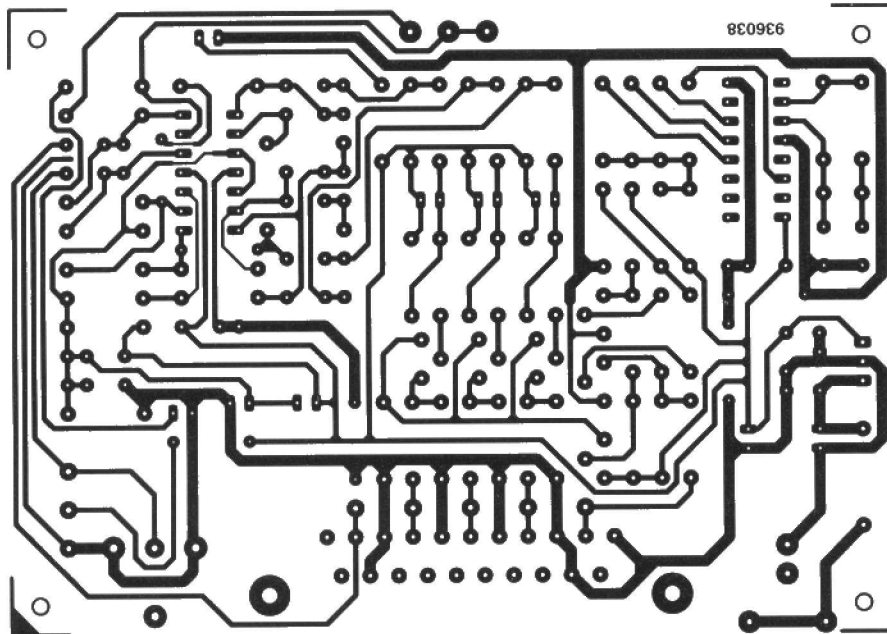


Fig. 5. Track layout (direct reading) and component overlay of the circuit board for the TV sound-to-light unit (PCB available ready-made through the Readers Services).

COMPONENTS LIST

Resistors:

R1,R39 = 2k Ω
 R2 = 220k Ω
 R3,R5-R9,R28,R33 = 10k Ω
 R4,R16,R17,R21,R22,R23 = 56k Ω
 R10,R26,R29,R32,R38 = 390 Ω
 R11 = 330k Ω
 R12,R14,R15 = 1k Ω
 R13 = 22k Ω
 R18,R20 = 150k Ω
 R19 = 47k Ω
 R24,R27,R30 = 1M Ω
 R25 = 5k Ω
 R31 = 15k Ω
 R34-R37 = 82 Ω
 P1 = 470k Ω logarithmic

Capacitors:

C1 = 33pF
 C2 = 100pF
 C3,C11,C12,C20,C21,C23 = 100nF
 C4,C5,C15 = 470nF
 C6 = 10nF
 C7,C8 = 1nF
 C9,C10,C22 = 100 μ F 10V radial
 C13 = 1 μ F MKT
 C14 = 22 μ F 10V radial
 C16,C18,C24 = 10 μ F 10V radial
 C17 = 220nF
 C19 = 100 μ F 40V radial

Semiconductors:

D1-D11 = 1N4148
 D12 = 1N4001
 D13 = LED 3mm red
 T1,T2 = BC547B
 T3-T6 = BC557B
 IC1 = 4060
 IC2 = TLC274
 IC3 = 7805

Semiconductors:

K1 = Cinch socket.
 K2 = 21-way SCART socket, PCB mount, angled pins.
 K3 = Mains adapter socket, PCB mount.
 X1 = 4MHz quartz crystal.
 Mic1 = Electret microphone.
 Case: e.g., ESM EM14/03.
 Printed circuit board 936038 (see page 70).

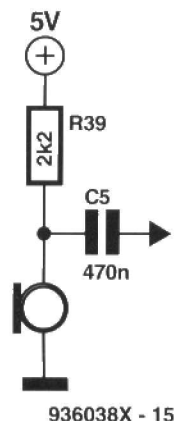


Fig. 6. Alternative connection schematic for two-wire electret microphones.

and smoothed by two diodes and a capacitor (for instance, D₇, D₈ and C₁₄), so that each driver is supplied with a clean direct voltage. The resistor across each smoothing capacitor (for instance, R₂₄) enables the capacitor voltage to decrease after a short while after the input signal has disappeared. This is done to give the sound-to-light unit a fairly 'calm' behaviour, avoiding a too fast response to sound changes. The output signal of each driver transistor is sent to the respective RGB input via a current limiting resistor of 82 Ω.

The circuit diagram shows that the RGB driver transistors are supplied via a series transistor, T₃, which acts as a switch, and so enables a simple kind of synchronisation to be realized. The switch is closed for 60 μs, which corresponds to the length of a picture line. Each period of 60 μs is headed by a synchronisation pulse of 4 μs, which serves to inform the TV that a new line is about to be written. The synchronisation pulse is sent to the TV set via R₃₄ and the respective pin on the SCART socket. To make sure that each line period has a total length of 64 μs, the switching signals are derived from a crystal oscillator with associated divider, IC₁. The 4-MHz quartz clock signal is divided by 256 (28), which gives a line frequency of 15.625 Hz, corresponding to a period of 64 μs.

Finally, the circuit is powered by a mains adaptor with a direct output voltage between 9 V and 12 V. The adaptor output voltage is stepped down to 5 V by regulator IC₃.

Construction

The artwork of the printed circuit board designed for the TV sound-to-light unit is given in Fig. 5. This board is available ready-made through the Readers Services.

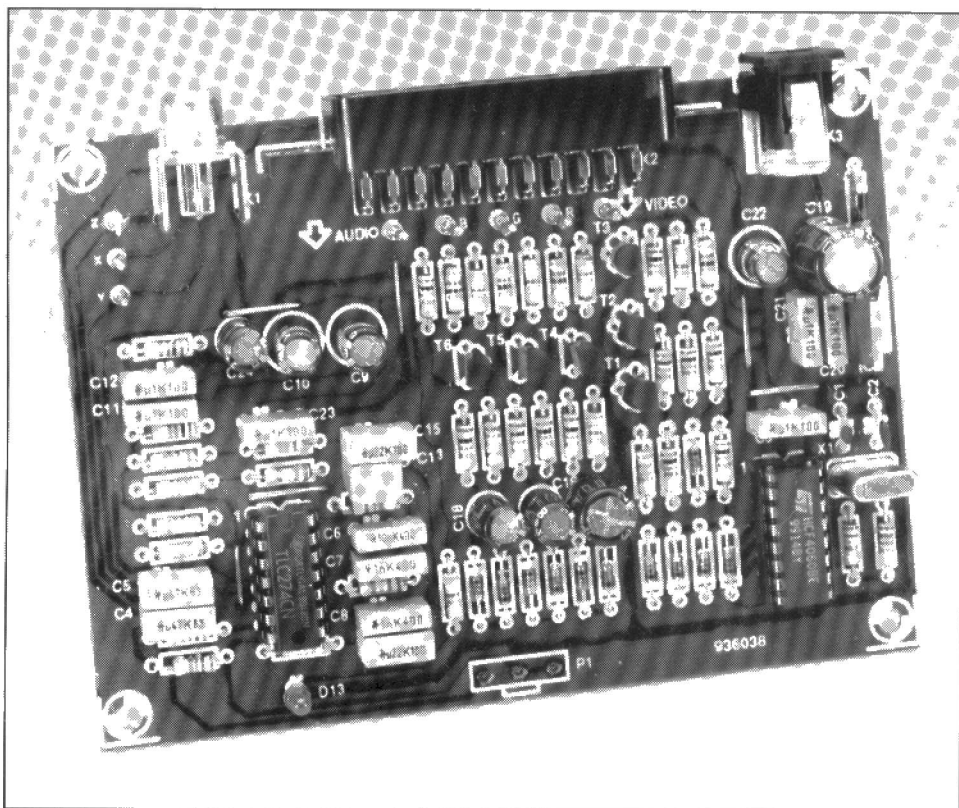


Fig. 7. Fully populated circuit board.

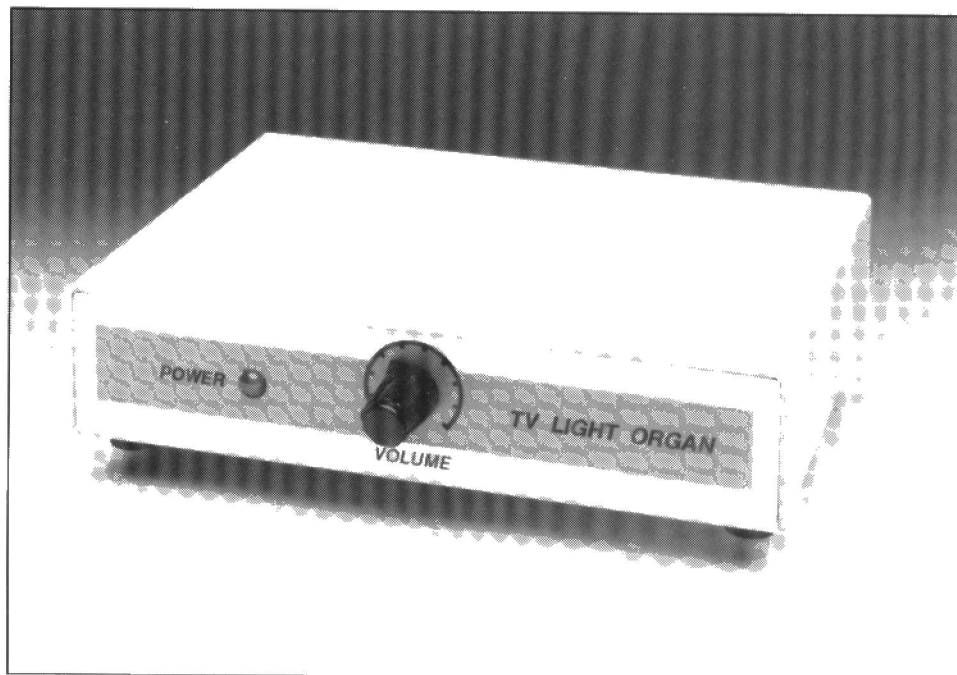


Fig. 8. Prototype of the TV sound-to-light unit mounted into a plastic enclosure.

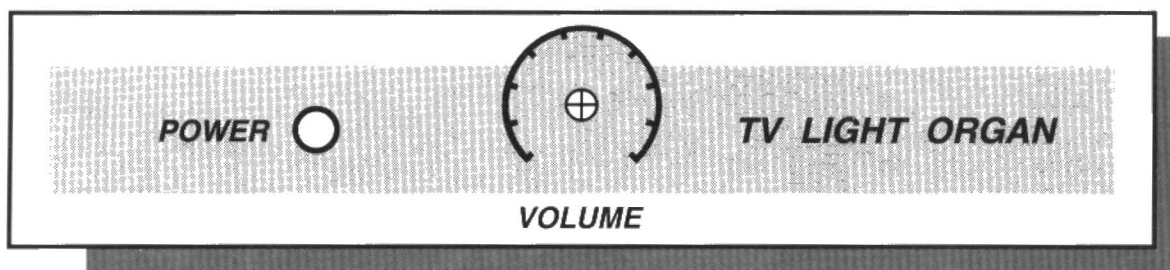
Start the construction by fitting all wire links, then the IC sockets. Solder carefully to avoid a long fault-finding session later. Next, fit all other parts, keeping the larger ones (for instance, the SCART socket and potentiometer P₁) till the last. The SCART socket is first secured to the PCB by inserting its plastic fixing pins into the two holes in the PCB. Next, solder the socket pins.

Resistor R₃₉ is not fitted on to the board, but connected to the electret microphone as a 'flying' part. If the microphone is a type with three terminals, it is connected as shown by the

circuit diagram. If you happen to have a two-terminal type, connect it as shown in Fig. 6. If you wish to use the line input only, Mic₁ and R₃₉ may, of course, be omitted.

The board is ready for fitting into a suitable enclosure after it has been populated (Fig. 7), and the solder work carefully inspected. The prototype shown in Fig. 8 should give you an impression of how we did the finishing touch to the unit. The design of a front panel for the TV sound-to-light unit may be copied from Fig. 9.

Connect the unit to the mains adap-



936038X - F

Fig. 9. Suggested front panel design.

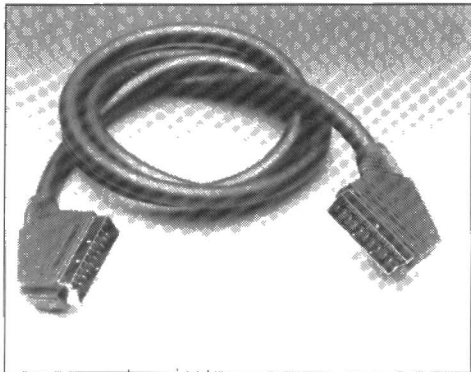


Fig. 10. The sound-to-light unit is connected to the TV set via a ready-made SCART cable.

tor, taking good care to observe the polarity of the d.c. supply voltage. The circuit is protected against reverse supply voltages by diode D_{12} . If everything is in order, the 'power' LED should light after connecting the mains

adaptor.

Next, connect the circuit to the TV set via ready-made SCART cable (Fig. 10). The pinning of the SCART plugs on the cable, and that of the socket on the TV, is shown in Fig. 11. Also connect the microphone, or the line input signal.

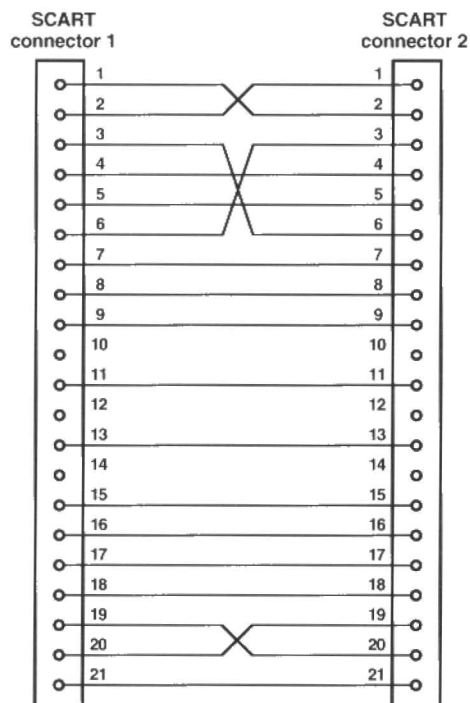
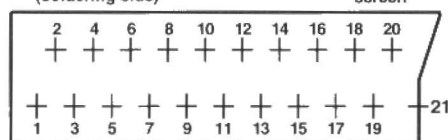
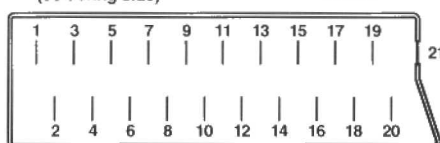
Switch the TV to external A/V, and adjust the input sensitivity of the sound-to-light unit until the desired visual effect is achieved.

Some experiments

A few suggestions are given for those of you who wish to adapt the circuit to personal requirements. The response of the circuit to changes in the input signal may be speeded up by decreasing the values of capacitors C_{14} , C_{16} and C_{18} . Note, however, that this causes a slightly blurred picture, and

unclear colour transitions. Similarly, the response of the circuit is slowed down by increasing the values of the above capacitors.

The 'low' frequency limit of the filter in the unit may be lowered by changing R_{18} and R_{20} into, for instance, 220 k Ω , and R_{19} into 100 k Ω . This modification causes the circuit to respond stronger to the lowest frequency components, and less to high-frequency components. To achieve a better separation of the low, middle and high components, the value of R_{19} may be lowered to 22 k Ω , while C_6 is changed into 22 nF.

SCART socket
(soldering side)SCART plug
(soldering side)

936038X - 16

Fig. 11. Want to make a SCART cable yourself? Here are the plug and socket connections.

ELECTRONICS SCENE

Surface mount crystal from IQD

International Quartz Devices (IQD) has available a surface mount version of the popular HC49/4H crystal. Designated the HC49/4HSMX, the new version has a footprint of only 4.9x13.4 mm and is 4.3 mm high.

IQD Ltd, Crewkerne, Somerset TA18 7AR, England. Telephone (0460) 77155.

Embedded controller handbook

Microchip's new *Embedded Controller Handbook* is packed with ideas and advice for system designers and application programmers. It contains almost a thousand pages of technical reference material and covers the whole range of Microchip's PIC16/17 8-bit microcontrollers and speciality non-volatile memory products.

Arizona Microchip Technology Ltd, Unit 3, The Courtyard, Meadowbank, Furlong Road, Bourne End SL8 5AJ, England. Telephone (0628) 850 303.

Statek franchise for ACT

Quartz crystal manufacturer and distributor ACT (Advanced Crystal Technology) has signed a franchise agreement with the specialist quartz crystal firm, Statek Inc. of Orange, California.

ACT, 9 Kingfisher Court, Hambridge Road, Newbury RG14 5SJ, England. Telephone (0635) 528 520.

Good for Europe?

The Japanese government is about to abandon Japan's analogue high-definition television system, which lags behind America's digital technology despite decades of development. This decision makes it probable that a **worldwide HDTV standard** based on America's may at last emerge. If so, a sigh of relief will be heard in the larger part of the world—particularly in the corridors of Thomson and Philips, both members of the US association of HDTV manufacturers.

Nevertheless, Europe will lose out on some aspects, because, although both the US and Europe have chosen MPEG compression, the US has opted for vestigial sideband (VSB). The European 'standard' for digital TV is quadrature amplitude modulation. However, this should not matter much since the European mass market for HDTV equipment is not likely to come about until the early part of the next century.

Apple at the top

Dataquest, the influential US analyst firm, has announced that Apple Computer Inc. was the largest PC maker in the USA in 1993, just ahead of rivals IBM and Compaq. Apple gained 14.1% of the market, IBM 13.9% and Compaq 10%.

Eighth North Wales

Radio & Electronics Show

The Eighth North Wales R&E Show will be held on 5 and 6 November 1994 at the Aberconwy Conference Centre & The New Theatre, Llandudno. The Show opens at 10.00 a.m. both days. Entrance fee £ 1.50; under the age of 14 admission is FREE.

North Wales Radio Rally Club, Annecott, Hylas Lane, Rhuddlan, Clwyd LL18 5AG. Telephone/fax (0745) 591 704.

Emulation support for embedded 80386CX/EX

German in-circuit emulator manufacturer Hitex (see advert on p. 36) have announced the first full in-circuit emulators for the new Intel 80386CX/EX embedded microprocessors. Using the existing PC-based T32/386SX emulator as a base, the CX version allows true in-circuit emulation of the CPU up to 20 MHz (25 MHz to special order) in both 100PQFP and MQFP packages.

A comprehensive information pack is available from Hitex covering all 80386 family development tools.

Hitex (UK) Ltd, Sir William Lyons Road, Science Park, Coventry CV4 7EZ, England. Telephone (0203) 692 066.

SpiceAge 3 for Windows

V3 of SpiceAge for Windows gives an order of magnitude of speed rise for logic simulation over SpiceAge 2, previously believed to be the fastest analogue simulator of its type available. V3 benchmarks at 9 s on the digital test compared with 120 s on V2. Speed gains are also apparent on some analogue circuits.

To support this, a new 32-channel logic analyser display is available, more digital models are provided and input signal bus structures are supported. The Zetex SPICE library of analogue semiconductor models is shipped with V3 and the analogue side is further expanded by a brand new operational amplifier especially developed to exploit the linear extrapolation pragmas provided in SpiceAge's polynomial functions. Not only is this topology more accurate than many SPICE models but is faster to analyse. **Those Engineers Ltd, 31 Birkbeck Road, London NW7 4BP, England. Telephone 081 906 0155.** (See also advert on p. 59).

New autorouter from ULTimate

ULTimate's new Ripup & Retry Autorouter, the ULTroute GXR, a Windows-based product, is a sophisticated autorouter offering very high completion rates whilst remaining user interactive and friendly. ULTroute GXR gives the user control over cost factors and strategies, allowing him to influence the behaviour of the router and therefore customise the router to his type of designs.

There are also new versions (4.50) of ULTboard and (1.50) ULTicap. Both are now 32 bit using a Windows compliant DOS extender.

ULTboard, the first PCB design package to benefit from Real Time Design rule checking has been enhanced with powerful Trace Shove and Polygon features.

ULTicap offers several powerful automatic features that reduce editing time, including Autowire, Auto Snap to Pin, Auto Junction and Real Time Electrical Rule Checking.

ULTimate Technology (UK) Ltd, 2 Bacchus House, Calleva Park, Aldermaston RG7 4QW, England. Telephone (0734) 812 030. (See inside front cover).

New from Maplin

A combined **clock and thermometer**, with an outdoor temperature probe, that can display either °C or °F. The LCD alternates between time and temperature readings at three second intervals. The unit, type-coded BU77J, measures 68x52x16 mm, and is priced at £ 9.95 (incl. VAT).

A range of **high power speakers**, specially designed for use in cars. Power rating from 50 W to 200 W. Prices range from £ 34.95 to £ 149.95 each (incl. VAT).

The **Fox Wireless Home Alarm** has been specially designed to help protect the home or office without spoiling the decoration with yards of ugly wiring. Because there is no wiring between the intrusion detectors and the control panel, the system can be easily installed by anyone with average DIY skills. Price £ 99.99 (incl. VAT).

The **Auto-inflating digital blood pressure monitor** is an easy to use, digital, blood pressure tester designed to remove the complexities of measuring blood pressure and pulse rate, particularly for those who are not familiar with the technique. Price £ 74.95 (incl. VAT). **Maplin Electronics, P.O. Box 3, Rayleigh SS6 8LR, England. Phone (0702) 552 911.**

Z-Match for Windows

The paper Smith Chart, invented over 50 years ago provides a graphical method for solving impedance matching and transmission line problems. Number One Systems' new Z-Match for Windows program greatly enhances the usefulness and accuracy of Smith Chart techniques, and adds a wide range of valuable Radio Frequency Engineering utilities.

An immediately apparent advantage of Z-Match for Windows is that it works directly with actual lengths of transmission line and actual resistance and reactance values, eliminating the need for normalisation.

Z-Match for Windows displays impedance values produced by Analyser III, Number One Systems' simulation tool for analogue circuits. In combination, these packages cover the vast majority of design and analysis problems likely to be faced by engineers and students working at RF.

Number One Systems, Harding Way, St. Ives, Huntingdon, England. Telephone (0480) 461 778. (See also p. 4)

LETTERS

Dear Editor—I have found that the BFX36 used in the '100 W high-end power amplifier' (March 1994) is no longer available. In fact, I was told that production of this device was discontinued in 1991. This does not seem in line with your recently stated policy of trying to only publish designs for which the components are actually available. Would the designer please give advice on component values for the amplifier input stage using more readily available transistors, such as the ZTX851, ZTX951. I appreciate that the amplifier performance may not be quite as good with discrete transistors, but it would at least allow the design to be built. I have built a number of your projects in the past which I have always found to be very good and I find it annoying that I cannot build this amplifier to go with them.

Simon Platt, Bedford

We are aware of the problems regarding availability of the BFX36. Although the device is obsolescent, stocks are still available here and there, more particularly from one of our advertisers, C-I Electronics, P.O. Box 22089, 6360 AB Nuth, the Netherlands. Fax +31 45 241 877. In fact, the BFX36 and its complement, the 2N2914, are listed in C-I's advert on p. 33 of our March 1994 issue.

Our Central Design Department are examining the specifications of several possible replacements for the BFX36/2N2914. When suitable types have been found, the relevant update information will be published in this magazine.

Dear Editor—I have just completed the construction of the 'Digital dial' described in the January 1994 issue. May I relate some quite interesting matters that arose during construction and testing?

My mistake (discovered after two days) was to use a 74HC4060 instead of the specified 4060. I only did this because I happened to have the 74 version and not a 4060. It does not work! I don't know why. They are supposed to be compatible. After the change,

the 'dial' worked really well.

I have fitted it to my AR88LF. The display is fitted behind the 'window' on the front panel which should contain an 'S' meter. The rest is in a box resting on the IF transformers. I tried to use the 6.3 V heater supply, as that is available at the dial light, but I could not get a suitable transformer. In the end, I put a mains transformer in the box with the rest of the components.

If any of your readers have in mind making a 'Digital Dial' for their AR88, I can let them have details of an easy way of obtaining the LO feed without any soldering or up-ending the receiver (which must weigh a good 25 kg).

One feature of the 'dial' I should mention is that the three horizontal bars of the first digit in the display do not attain full brilliance. Perhaps this is due to all being fed from the same pin of the 4543? No great disadvantage, but can this be overcome?

On a completely different tack, I was asked the other day what SCART stood for. I do not know—do you? Is it an acronym or what is it (apart from a standard socket for computers)?

C.E.H. Benson, Warrington.

Thanks for your letter, which we feel sure will be of interest to many other readers.

The matter of the brilliance of the first three horizontal bars has been referred to the designer. As soon as his answer is to hand, we will write to you.

SCART is an acronym of Syndicat des Constructeurs d'Appareils Radiorécepteurs et Téléviseurs, the French association of radio and television manufacturers. This association decided in the early 1980s to terminate various inputs to, and outputs from, TV receivers into a 21-way socket, which has since become a European standard.

Dear Editor—I read with interest your article on the SCMS inhibitor for DAT machines (**Copybit Eliminator** – February 1994). I would like to make this unit for use between two Sony Portable DATs, i.e., the D3 and D7 machines. A separate box would be required with either coax or fibre optic connectors.

I am a musician, not a technical person, but I can use a soldering iron, so any help you can give me would be gratefully appreciated. I presume any components required can be purchased from Maplin or any other such supplier.

G. Drucquer, Frimley Green.

We are currently working on a stand-alone version, i.e., one that can be inserted between two DAT recorders as you require. We plan to publish the relevant article in our July/August 1994 issue. Briefly, the design will consist of the 'Digital audio enhancer' (February 1993) in slightly modified form, the 'Copybit eliminator', and a small add-on board. All this is, however, tentative and will depend on the tests our design department are currently carrying out proving successful.

Dear Editor—I have sent for the PIC programmer project that appeared in the March 1994 issue of your magazine and in the article eight 499 kΩ 1% resistors are needed. I have looked in various catalogues and TV and electronics magazines and I cannot find a source for such components. Please could you tell me where I could find them.

Why didn't you use presets or if these were not accurate enough, why didn't you use multiturn presets.

Have you have ever considered having full kits (incl. all components) for your projects.

M. McCabe, Redcar

Precision 1%, and even 0.1%, resistors are available from specialist audio/hi-fi component retailers. You may, for instance, try Viewcom—see pages 8 & 9 of our March and April 1994 issues. Complete kits are available from C-I Electronics—see the advert on p.33 of our April 1994 issue.

Presets cannot be expected to give anywhere near the same performance as precision resistors, but we have, nevertheless, passed your query to the designer.

As international book/magazine publishers, we cannot go into the specialist electronics trade, but leave this to the experts: our advertisers and other electronic component retailers.

COMPONENT RATINGS

In resistor and capacitor values, decimal points and large numbers of zeros are avoided wherever possible. Small and large values are usually abbreviated as follows:

p (pico-)	= 10 ⁻¹²
n (nano-)	= 10 ⁻⁹
μ (micro-)	= 10 ⁻⁶
m (milli-)	= 10 ⁻³
k (kilo-)	= 10 ³
M (mega-)	= 10 ⁶
G (giga-)	= 10 ⁹

less otherwise specified.

The direct working voltage of capacitors (other than electrolytic or tantalum types) is assumed to be ≥60 V. As a rule of thumb, a safe value is about 2× direct supply voltage.

Direct test voltages are measured with a 20 kΩ/V meter unless otherwise specified.

Mains (power line) voltages are not listed in the articles. It is assumed that our readers know what voltage is standard in their part of the world.

Readers in countries that use 60 Hz supplies, should note that our circuits are usually designed for 50 Hz. This will not normally cause problems, although if the mains frequency is used for synchronization, some modification may

be required.

The international letter symbol 'U' is used for voltage instead of the ambiguous 'V'. The letter V is reserved for 'volts'.

The size of a metric bolt or screw is defined by the letter M followed by a number corresponding to the overall diameter of the thread in mm, the × sign and the length of the bolt or screw, also in mm. For instance, an M4×6 bolt has a thread diameter of 4 mm and a length of 6 mm. The overall diameter of the thread in the BA sizes is: 0 BA = 6.12 mm; 2 BA = 4.78 mm; 4 BA = 3.68 mm; 6 BA = 2.85 mm; 8 BA = 2.25 mm.

Note that nano-farad (nF) is the international way of writing 1000 pF or 0.001 μF. Resistors are 1/3 watt, 5% metal film types un-

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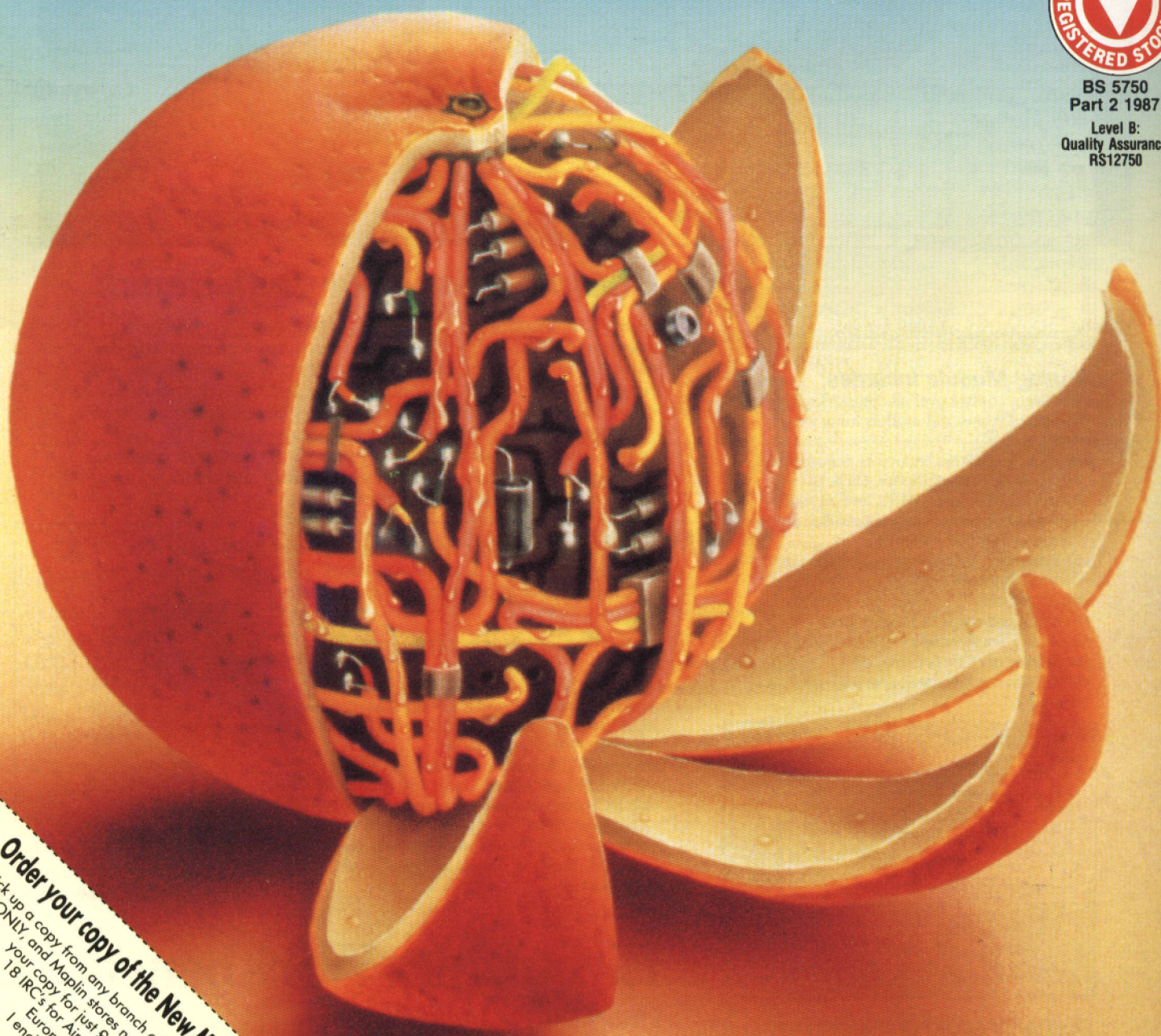
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